Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
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A FEASIBILITY STUDY OF A THERMOSYPHONING RIG

by

J.-C. Amrouni and S. Nijhawan
Idea Research

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Research report

A FEASIBILITY STUDY OF A THERMOSYPHONING TEST FACILITY

A report prepared by J-C Amrouni and S. M. Nijhawan of Idea Research, Toronto, Ontario, under contract 03SQ.87055-3-4122 to the Atomic Energy Control Board, Ottawa, Canada.

ABSTRACT

This report covers the work performed to generate a conceptual design of a thermosyphoniny test facility. Scaling methods have been reviewed; and a two phase scaling technique has been applied to determine the geometry and specifications of the facility. The instrumentation and the data acquisition systems have been defined such as to provide the most needed information on two phase thermosyphoning phenomena. Particular attention has been paid to the scaling of the primary heat transport system which consists of a figure-of-eight loop with five channels per pass and seven half-length, full-diameter heater elements per channel. The facility can be defined as "half-length, half-height facility" with decay power capabilities for the primary system and full power for the secondary system.

RÉSUMÉ

Le présent rapport traite du travail éffectué pour concevoir une installation d'essais de thermosiphon. On a examiné les méthodes de réduction à l'échelle, et on a retenu une méthode de réduction diphasique pour déterminer les caractéristiques géométriques et les spécifications de l'installation. Les systèmes d'instrumentation et d'acquisition de données ont été définis pour fournir l'information vraiment nécessaire à la compréhension des phénomènes de thermosiphon diphasique. Une attention particulière a été accordée à la réduction du système caloporteur primaire qui comprend une boucle en forme de huit, cinq canaux par passage et sept éléments chauffants de plein diamètre et de demi-longueur par canal. L'installation peut être définie comme une "installation de demi-longueur, demi-hauteur", avec capacités de puissance, résiduelle pour le système primaire, nominale pour le système secondaire.

DISCLAIMER

The opinions expressed in this report are those of the authors and do not necessarily reflect those of the Atomic Energy Control Board. The authors do not assume liability with respect to any damage or loss incurred as a result of the use made of the information contained in the publication.

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GENERAL INTRODUCTION

The present report on the feasibility study of a thermosyphoning rig is divided into seven sections.

The first section analyses the different scaling laws that can be applied for the scaling of a Candu reactor and makes a recommendation on the appropriate scaling for the facility.

The second section defines the conceptual design of the facility using the recommended scaling laws.

The third section is a computer simulation of the scaled down facility which compares the analysis results with operational data of a Candu 600.

The fourth section defines the instrumentation and data acquisition system that would be required to obtain useful experimental data from the facility.

The fifth section gives a set of specifications for the different components of the facility for future procurement and costing purposes.

The sixth section defines the test matrix of the experiments that are intended to be performed with the thermosyphoning facility. The test matrix is based on the phenomenology that is at present uncertain in a Candu reactor.

Finally the seventh section gives a brief description of the general layout of the facility.

Computer codes listings and output have benn regrouped outside the main body of this report and attached in appendices, since they are not necessary for the overall understanding of the report.

SECTION 1

- SCALING -

A. INTRODUCTION

Scaling means approaching a mathematical identity of analogous physical systems. When two different systems satisfy the same set of equations (conservation equations and equation of state) that completely describes the behaviour of one of the systems, either of the systems may be employed to describe the other.

Scaling is the single most important issue in the conceptual stage of experiments that faithfully aim at dynamically simulating the transients of interest of a system as large and complex as the Candu 600. For this study, similarity relations between the experimental setup (the proposed thermosyphoning facility) and the Candu must be established.

The Candu systems involve complex geometric and performance characteristics. The obvious question to be addressed is "what is the optimum scale model that will most economically and best reproduce the transients so that they can be quantified ?". The main idea is that results of simulated accidents cannot all be checked in the reactor. The results, however, can employed as a guide to safety analysis for code verification and model development. For justifiable application of scaled experimental results to a full scale real power plant, the scaling rationale must be sound and valid. Results of experiments on facilities that are not properly scaled, when applied to normal operation or as a guide to post accident handling of the power plant may lead to expensive errors. In its totality the complex Candu system cannot be scaled while maintaining true similarity but a judicious scaling choice can reduce distortions.

Reproduction of both hydrodynamic and thermohydraulic similarity on a model of dimensions and parameters (pressure, power, enthalpy,...) different than the reactor is rarely feasible unless only single thermohydraulic phenomenon is to be verified. For this reason model simulation has traditionally been based solely on hydrodynamic considerations. Under thermosyphoning conditions, the absolute and relative values of heat source and sink fluxes become more important.

B. OBJECTIVE

It is the purpose of this report to study the various scaling approaches and develop scaling criteria for a thermosyphoning facility that is able to simulate the behaviour of a Candu 600 under boundary conditions that have been postulated to produce thermosyphoning flows. One example of that is the loss of class IV power to the station.

The scaled facility would represent one figure of eight loop and contain all of the representative system components that are considered important.

C. BACKGROUND

There are two basic scaling approaches; one (volume scaling) preserves the time scale of phenomena, while the second (linear scaling) reduces the time scale.

Scaling laws have been developed for both single and two phase flow conditions. The two are not mutually exclusive but most of the analytical work has been done for single phase scaling. There are basic uncertainties in the way the two phase flow equations must be formulated for all phase and flow transitions (one fluid homogeneous versus drift flux versus two fluid separated flow.). Then there are uncertainties in the range of validity of individual two phase thermal and hydraulic correlations and in the criteria for flow and heat transfer regime transitions. Single phase conservation equations can be reasonably solved as the constitutive relations are well established.

Most of the scaling studies exclude the effect of using a different heat transfer medium. Heisler (Reference 1) analysed the effects of using water to simulate liquid metal (NaK) natural circulation. In our case the obvious choice for working fluid is light water as opposed to heavy water in the Candu. Scaling effects of this decision should also be analysed.

Ybarrando et al. (Reference 2) investigated scaling laws for LOFT and analysed the effect of the scaling compromises they selected.

Linear scaling was investigated for Semiscale Facility (Reference 3) by Larsen et al. and it was concluded that it would distort the geometry in the test facility. A similar conclusion was arrived at in Reference 2. A linear scaling by a scaling factor sf means that areas are scaled by sf^2 and volumes by sf^3.

Carbiener et al. (Reference 4) investigated linear scaling and break area to volume scaling for modelling blowdowns. They concluded that use of the linear scaling technique, preserving area ratios and relative linear dimensions while reducing the time scale, is most appropriate in the subcooled portion of the blowdown. Volumetric scaling, on the other hand they conclude, preserves the time scale and break area to volume ratio and is most desirable under two phase conditions. Linear scaling was also investigated for LOFT by Rose (Reference 5). That technique was followed in LOFT semiscale tests.

Nahavandi et al. (Reference 6) employed differential conservation equations to develop correspondence between the reactor and the model for three types of scaling procedures: time reducing, time preserving volumetric, and time preserving idealised model/reactor . They conclude that time reducing scaling is applicable only when gravity effects are small (large LOCA, water hammer).

For thermosyphoning the distortions produced by this similarity rationale are expected to be significant. It is suggested in this study that the time preserving power/volume scaling produces the least distortion. That is why that approach is widely used. "The critical heat flux and heat transfer characteristics as well as flow and enthalpy distribution in the reactor core are predicted from experimental data obtained from these fuel rod bundle tests." (Reference 6). The time preserving idealized model/reactor scaling law is based upon an equivalency of mathematical representation (like the mode link structure of FIREBIRD) of the reactor and the model.

Kocamustafaogullari and Ishii (Reference 7) developed two phase similarity laws for natural convection circulation loops using one-dimensional drift-flux model obtained from short time temporal averaging and the sectional area averaging. They also presented in this work scaling laws for single phase flows developed by Heisler (Reference 1) and Heisler & Singer (Reference 8). Results of (Reference 7) are discussed further in this report.

Single phase scaling laws for FLECHT SEASET (Full-Length Emergency Cooling Heat Transfer Systems Effects Tests) are described in (Reference 9). It is confirmed in this report that a volume-scaled test facility in which pipe flow lengths and hence the time are preserved would produce the most prototypical results. Power to volume scaling laws have been presented by Zuber (Reference 10). Single phase differential conservation equations are employed for time preserving scaling methods.

D. SCALING FOR THE THERMOSYPHONING FACILITY

Scaling laws are derived for the thermosyphoning facility for single phase flows and results of analysis for two phase flows of (Reference 7) are presented. The single phase scaling procedure development draws from References 1 through 10. Some scaled numerical system geometric and thermohydraulic parameters for the thermosyphoning facility are also presented.

1. Scaling Parameters for Single Phase Flows in a Candu 600

Generalised conservation laws for mass, momentum and energy along with the equation of state are employed. The objective is to derive scaling laws and not to solve the equations. Therefore, the equations are kept in their general form. In this form the equations are valid for homogeneous two phase flows as well as single phase flows.

1.1 Conservation Laws

Conservation equations are presented in differential form to describe the fluid at any point in the system. Most of the symbols used are standard and where necessary they are described.

1.1.1 Mass

$$\frac{d}{dt}(\rho A) + \frac{d}{dt}(\rho v A) = 0 \qquad \text{or,}$$

$$\frac{d\rho}{dt} + v\frac{d\rho}{dz} + \rho\frac{dv}{dz} + \frac{\rho v}{A}\frac{dA}{dz} = 0 \tag{1}$$

1.1.2 Momentum

$$\frac{d}{dt}(\rho A v) + \frac{d}{dz}(\rho A v^2) + A\frac{dp}{dz} + \tau_w P + \rho g A \cos\theta = 0$$

or

$$\rho\left(\frac{dv}{dt} + v\frac{dv}{dz}\right) + \frac{dp}{dz} + \frac{t_w P}{A} + \rho g \cos\theta = 0 \tag{2}$$

inertia pressure wall shear gravity

1.1.3 Energy

$$\frac{d}{dt}\left(\rho A\left(e+\frac{v^2}{2}\right)\right)+\frac{d}{dz}\left(\rho A v\left(e+\frac{v^2}{2}\right)\right)+\frac{d}{dz}(\rho A v)+q''P+A v\rho g\cos\theta = 0$$

for $e = h - P/\rho$

$$\rho\left(\frac{dh}{dt} + v\frac{dh}{dz}\right) - \left(\frac{dp}{dt} + v\frac{dp}{dz}\right) - v\tau_w\frac{P}{A} - \frac{q''P}{A} = 0 \tag{3}$$

1.2 Equation of State

$$\rho = \rho\,(h,p) \tag{4}$$

1.3 Constitutive Laws for Shear and Heat Transfer

$$f = f\,(e/D, Re) = \frac{4t_w}{1/2\ \rho v^2} \tag{5}$$

$$Nu = Nu\ (\rho, v, D, \mu, k, C_p, \ldots..) \tag{6}$$

The above equations are derived for single phase flows but are applicable to two phase flows under conditions of thermal equilibrium and no slip between the vapor and liquid phases.

1.4 Time Preserving Scaling

In order to develop time preserving similarity between the full

scale reactor and the rig (model) the following dimensionless parameters are introduced. They are used later to operate upon the conservation equations. Parameters with subscript 'o' correspond to a reference scale of the reactor or of the model.

$$(Z / Z_o) = Z^+ \qquad (7.1)$$

$$(t / t_o) = t^+ \qquad (7.2)$$

$$(A / A_o) = A^+ \qquad (7.3)$$

$$(o / o_o) = o^+ \qquad (7.4)$$

$$(v / v_o) = v^+ \qquad (7.5)$$

$$(p / p_o) = p^+ \qquad (7.6)$$

$$(h / h_o) = h^+ \qquad (7.7)$$

$$(q'' / q''_o) = q''^+ \qquad (7.8)$$

$$8\tau_W / (f_o P_o v_o^2) = \tau_W^+ \qquad (7.9)$$

Introducing the above dimensionless parameters into the conservation equations we obtain,

Mass

$$\frac{d\rho^+}{dt^+}\frac{v_o t_o}{z_o} v + \frac{d\rho^+}{dz^+}\frac{v_o t_o}{z_o} o + \frac{dv^+}{dz^+}\frac{v_o t_o}{z_o}\frac{\rho^+ v^+}{A^+}\frac{dA^+}{dz^+} = 0 \qquad (8)$$

Momentum

$$\rho^+ \left(\frac{dv^+}{dt^+} + \frac{v_o t_o}{z_o} v^+ \frac{dv^+}{dz^+} \right) + \frac{P_o t_o}{v_o \rho_o z_o}\frac{dp^+}{dz^+}$$

$$+ \frac{P_o f_o v_o t_o}{8A_o}\frac{\tau W^+ p^+}{A^+} + \frac{g t_o}{v_o}\rho^+ \cos\theta = 0 \qquad (9)$$

Energy

$$\rho^+\left(\frac{dh^+}{dt^+}\frac{v_o t_o}{z_o} v + \frac{dh^+}{dz^+}\right) - \left(\frac{P_o}{\rho_o h_o}\frac{dp^+}{dt^+}\frac{v_o t_o}{z_o}\frac{P_o}{\rho_o h_o}\frac{dp^+}{dz^+}\right)$$

$$- \left(\frac{P_o f_o v_o t_o}{8A_o}\frac{P_o}{\rho_o h_o}\frac{\rho_o v_o z_o}{P_o t_o}\frac{v_o t_o}{z_o}\right) v^+ \tau^+ \frac{p^+}{A^+}$$

$$- \frac{P_o q''_o t_o}{A_o \rho_o h_o}\frac{q^+ p^+}{A^+} = 0 \qquad (10)$$

The comparison of the new set of conservation equations (Equations 8, 9 and 10) to the original set (Equations 1, 2 and 3) shows that the two sets are identical if:

$$(vt/z)_o = \text{constant for rig and reactor} \quad (11)$$

$$(\rho t/v\rho z)_o = \text{constant for rig and reactor} \quad (12)$$

$$(Pfvt/A)_o = \text{constant for rig and reactor} \quad (13)$$

$$(gt/v)_o = \text{constant for rig and reactor} \quad (14)$$

$$(Pq"t/A\rho h)_o = \text{constant for rig and reactor} \quad (15)$$

$$(p/\rho h)_o = \text{constant for rig and reactor} \quad (16)$$

Equation 16 is satisfied if rig and reactor have the same fluid and the rig is scaled such that the thermosyphoning phenomena of interest occur at the same pressure.

It is quite difficult to justify using heavy water as the fluid medium in the rig unless it is demonstrated that the momentum and heat transfer mechanisms and hence correlations are different in light and heavy water systems. All of the safety analysis and the supporting model development and experiments have been performed using light water. We intend to investigate potential sources of scaling error by comparing thermodynamic properties of light and heavy water, but the use of light water looks, a priori, like the right scaling decision whose effects should be considered in the analyses of the results. It would also be the right economic decision.

Tables I.1 to I.15 show the value of the non dimensional parameter $\rho/\rho h$ for light and heavy water at saturation and at various qualities for different pressures. It was developed using the saturation thermodynamic data of Tables 16 and 17. For two phase mixtures:

$$\rho = (x/\rho_g + (1-x)/\rho_f)^{-1}$$

$$h = (x/h_g + (1-x)/h_f)^{-1}$$

The parameter, $\rho/\rho h$, for heavy water is approximately 9 to 7% lower at saturation than the corresponding one for light water, but the difference gets smaller under two phase conditions. Perhaps a scaling down of operating pressures may be necessary to compensate for this seemingly unavoidable discrepancy.

During further development of the scaling methodology this parameter is assumed to be the same for both light and heavy waters at equal pressures.

Similarity parameter (v.t/z) given by Equation 11 is similar to what is termed the Strouhal Number, which has physical significance, in general, as a measure of the ratio of the

steady to unsteady inertial forces. It appears in the continuity equation and also scales the momentum and enthalpy fluxes. If the scaled model and the reactor have the same Strouhal Numbers then both systems will have the same rates of changes in mass, momentum and enthalpy (a necessary but not sufficient condition as other criteria must be met simultaneously). Therefore, for transients with large changes in mass, momentum or energy content, the Strouhal Numbers must be held constant to get reactor response. For a transient in a mode with the "same" fluid pressure, equation 10 indicates that with Strouhal Numbers being equal, the rate of pressure drop will have the same effect on the model and the reactor. One step towards meeting the requirement of equal Strouhal Numbers is to have equal time scales so that resultant rates of changes in momentum and energy are similar. Once the time scale is preserved (isochronous events in the Facility and Candu), Equation 11 yields:

$$(v/l)_F = (v/l)_C \qquad (17)$$

where subscripts F and C stand for the proposed Facility and Candu, respectively. The subscripts 'o' have been dropped for clarity and the axial distance is given by l.

$$v_F / v_C = l_F / l_C \quad \text{or} \quad v_R = l_R \qquad (18)$$

R stands for the ratio of parameters for the Facility and Candu. The volumetric flow rate is given by:

$$G = v.A$$

so that Equation 18 yields,

$$(v_F . A_F) / (v_C . A_C) = (l_F . A_F) / (l_C . A_C)$$

or

$$(G_F / G_C) = (V_F / V_C) \quad \text{or} \quad G_R = V_R \qquad (19)$$

or Volumetric Flow Rate Ratio = Volume Ratio

For assumption of equal densities of the working and modelling fluids (heavy water in CANDU versus light water in Facility) and occurance of phenomena at the same pressures, Equation 19 can also be used to express the ratio of mass flow rates:

$$(W_F / W_C) = (V_F / V_C) \quad \text{or} \quad W_R = V_R \qquad (20)$$

Equation 15 scales the effect of heat flux on energy transfer. For isochronous events occurring at the same presure and similarity (alas not equality) of parameter (p/o.h) given by Equation 16, the Equation 15 reduces to:

$$(P q" / A)_F = (P q" / A)_C \qquad (21)$$

If we require the flow lengths to be equal in order to satisfy the requirement for equal time scales and Equation 18, then,

$$(l.P.q'')_F / (A.l)_F = (l.P.q'')_C / (A.l)_C$$

$$\text{or } (Q / V)_F = (Q / V)_C$$

$$\text{or } (\text{Power/Volume})_F = (\text{Power/Volume})_C \qquad (22)$$

This indicates that the heat generation (or removal) per unit volume fo the Facility and the CANDU should be equal.
Equations 19, 20 and 22 give a constant volumetric scaliny factor:

$$Q_F / Q_C = W_F / W_C = G_F / G_C = V_F / V_C = t \qquad (23)$$

This scaling factor allows similarity in equations of mass and energy. Therefore, the effects of various processes described by these equations are preserved without any apparent distortion.

There are 4 basic terms in the momentum Equation 2 and (9). They are:

$$\rho \left(\frac{dv}{dt} + v \frac{dv}{dz} \right) = \rho^+ \left(\frac{dv^+}{dt^+} + \frac{v_o t_o}{z_o} v^+ \frac{dv^+}{dz^+} \right) \qquad \text{inertia term}$$

$$\frac{dp}{dz} = \frac{p_o t_o}{v_o \rho_o z_o} \frac{dp^+}{dz^+} \qquad \text{pressure term}$$

$$\frac{\tau_w P}{A} = \frac{p_o f_o v_o t_o}{8 A_o} \frac{t^+ p^+}{A^+} \qquad \text{shear term}$$

$$\rho g \cos\theta = \frac{g t_o}{v_o} \rho^+ \cos\theta \qquad \text{gravity term}$$

The effect of the inertia term has already been scaled by the proposed equality of Strouhal Numbers. While preserving the time scale, pressures, and equal gravity effects we assume that the fluid properties of D20 and H20 are equal.

Equations 12, 13, and 14 reduce to:

$$(v.l)_F = (v.l)_C \qquad (24)$$

$$(P.f.v / A)_F = (P.f.v / A)_C \qquad (25)$$

$$V_F = V_C \qquad (26)$$

Equations 17 and 26 lead to,

$$l_F = l_C \qquad (27)$$

This automatically satisfies Equation 24. Therefore, it becomes imperative to preserve elevations and velocities between the Facility and Candu. For equal lengths, the cross-section scaling is derived from Equation 23 as,

$$A_F / A_C = A_R = sf \qquad (28)$$

so that

$$D_F / D_C = D_R = A_R^{1/2} = sf^{1/2} \qquad (29)$$

The diameter ratio in the above equation is for flow diameters only. A different scaling is required for major heat transfer surfaces. Equation 25, for equal velocities between the facility and Candu, reduces to :

$$(P.f / A)_F = (P.f / A)_C \qquad (30)$$

From the integral form of the momentum integral equation, including the effects of minor losses, the above equation can be written (1) for integration around the loop as:

$$(f.l / D + \Sigma k)_F = (f.l / D + \Sigma k)_C \qquad (31)$$

This equation requires that the flow resistance similarity be satisfied for the whole loop. It does not have to be satisfied for each section separately. For any Candu pipe element a computer analysis based on the following can be made.

Equation 30 can be rewritten as,

$$(f_F.l_F)/ D_F + \Sigma k_F = (f_C.l_C)/ D_C + \Sigma k_C$$

The distributed minor loss coefficient k can be varied by suitable choice of large bend radii and variable orificing. It's value may have to be adjusted to get as close to the scaled area ratio, , as possible,

$$((f_F.l_F)/D_F).(D_C/(f_C.l_C)) =$$

$$1 + (\Sigma k_C - \Sigma k_F)\ D_C/(f_C.l_C) \qquad (32)$$

A suitable correlation for friction factor dependence upon Reynold's number is introduced. For example, Beattie's formula can be applied,

$$f = .037\ (\rho vD / \mu)^{-0.17} \qquad (33)$$

In its general form, the above equation can be written as,

$$f = C_1\ (\rho vD / \mu)^{-n} \qquad (34)$$

So that for equal fluid properties,

$$f_F / f_C = ((V_F/V_C).(D_F/D_C))^{-n}$$
$$= l_R^{-n} A_R^{-n/2} \qquad (35)$$

where l_R and A_R are the length and area ratios between the Facility and Candu as defined in Equation 18 and 28. Equation 32 can now be written as,

$$(l_R^{-n} A_R^{-n/2} l_R)/A_R^{1/2} = 1+(\Sigma k_C - \Sigma k_F) D_C/(f_C . l_C)$$

or $A_R =$

$$(l_R^{(n-1)} (1+(\Sigma k_C - \Sigma k_F) D_C/(f_C l_C)))^{-2/(n+1)} \qquad (36)$$

For a length preserving scaling method,

$$l_R = 1$$

Equation 36 can be iterated for the possible values of Σk to arrive at the desired area ratio of sf. It should be noted that minor and major loss terms are interchangeable in Equation 31.

Following this volumetric scaling approach the flow lengths, the velocities and accelerations should be the same in the modelled Facility as in the Candu. When one preserves the real time aspect of the thermohydraulic processes, the areas are scaled by the scale factor sf. So pressure drop per unit length would be higher in the major system piping. The above analysis can be used to design the piping system with the minimum possible scaling distorsions by using variable orificing and larger radius bends. In the Candu figure of eight loop the major pressure drop may be in the pump while in the Facility the wall friction may dominate.

The scaling of heat transfer surfaces can be developed from the major scaling Equation 23,

$$sf = Q_F / Q_C = (q"_F A_{SF})/(q"_C A_{SC})$$

where A is the heat transfer area in the core and the steam generator. If N is the number of heat transfer surfaces of diameter D, then

$$sf = Q_F / Q_C = (q"_F / q"_C) \ (N \pi D l)_F / \ (N \pi D l)_C \qquad (37)$$

For the same heat flux, same lengths, we get,

$$sf = (N D)_F / (N D)_C \qquad (38)$$

One can theoretically vary both the number of heat transfer surfaces, N, and diameter, D. It is advisable, from the point of view of duplicating subchannel phenomena in the core and reflux condensation and flooding at steam generator tube sheet, to keep the diameter D the same and make N variable.

1.5 Scaling for Heat Losses

For an uninsulated pipe of inner radius r_1 and outer radius r_2, thermal conductivity k_p and inner and outer convective heat transfer coefficients h_i and h_o, respectively, the total heat loss to the environment at temperature T_{inf} from a fluid at constant temperature T_i is given by:

$$Q_{LC} = 2\pi L \left(T_i - T_{inf} \right) /$$

$$\left((1/r_1 h_i) + \ln(r_2/r_1) / k_p + (1/r_2 h_o)\right) \qquad (39)$$

In order to preserve the fluid enthalpy drop in the pipe, the heat loss from the pipe must be scaled down by the ratio of mass flow rates. For a scaling factor of sf the heat loss from the pipe in the facility must be sf of heat loss from the corresponding Candu pipe.

$$Q_{LF} / W_F = Q_{LC} / W_C$$

$$Q_{LF} = W_F / W_C \cdot Q_{LC} = sf \cdot Q_{LC} \qquad (40)$$

A first order analysis based upon the dominance and equality ouside heat transfer coefficients suggests that the relative heat loss from a pipe whose cross section area has been scaled down by sf is given by:

$$\frac{Q_{LF}}{Q_{LC}} = \frac{h\pi D\ l_F (T_i - T_{inf})_F}{h\pi D\ l_C (T_i - T_{inf})_C} = \frac{D_F}{D_C} = sf^{1/2} \qquad (41)$$

In other words the heat loss is $1/sf^{1/2}$ times the desired value. For long length of pipe it may cause distorsions. A computer program can be written to determine the optimum size and conductance of insulation so that the heat loss can be regulated. The pipe thickness cannot be arbitrarily varied. It may be determined only by the ASME code. The following equation can be employed along with equation (42) to design the insulation radius r_3 (insulation thickness = $r_3 - r_2$) and conductivity k_i.

$$Q_{LF} = sf \cdot Q_{LC} = 2\pi r_3 L \left(T_i - T_{inf} \right) /$$

$$\left(r_3/r_1 h_i + r_3 \ln(r_2/r_1)/k_p + \right.$$

$$\left. r_3 \ln(r_3/r_2)/k_i + 1/h_o \right) \qquad (42)$$

1.6 Linear Scaling

When flow lengths are scaled in a flow network, either the flow velocities that really are the crux of the thermohydraulic phenomena or the time scales of the thermohydraulic phenomena have to be altered. Linear scaling was investigated for LOFT Semiscale by Rose (Reference 5). This type of scaling is appropriate only for subcooled conditions wherein acoustic

phenomena predominate (Reference 4). Bubble formation and growth, phase separation, development of flow regimes, etc. will be distorted if they occur in the test under reduced time scale conditions. Time preserving volumetric scaling was later employed in the LOFT integral test facility (Reference 11). Heisler (Reference 1) also investigated linear scaling and found that both uniform linear and nonuniform nonlinear (different scaling ratios for lengths, diameters, etc.) produce flow and temperature distorsions.

Table III from reference 4 summarises the linear and volumetric scaling applications to a PWR geometry.

Linear scaling criteria are presented below.

In the development of a linear scaling approach to modelling, the symbols with an asterisk refer to the reactor thermal and thermohydraulic quantities while the same symbols without an asterisk refer to the modelled thermosyphoning facility. To the conservation equations for one dimensional flow (equations 1, 2 and 3) the following scaling relations are employed:

Time

$$t / t^* = \bar{T} \qquad (43)$$

Geometry

$$z / z^* = \bar{L} \qquad (44)$$

Velocity

$$v / v^* = \bar{L} / \bar{T} \qquad (45)$$

Heat generation per unit volume

$$Q / Q^* = \bar{Q} \qquad (46)$$

As discussed earlier, the modelled facility and the reactor operating conditions and fluid properties are assumed to be the same.

$$p / p^* = 1 \qquad (47)$$

$$h / h^* = 1 \qquad (48)$$

$$\rho / \rho^* = 1 \qquad (49)$$

$$\text{and} \quad \tau_w = f/8 \; \rho^* \; v^* \; \bar{L}^2 / \bar{T}^2 \qquad (50)$$

Substituting equations 46 through 52 in the conservation equations (1, 2 and 3) we get

$$\frac{d\rho^*}{d\bar{T}t^*} + \frac{\bar{L}}{\bar{T}} v^* \frac{d\rho^*}{dLz^*} + \rho^* \frac{d(\bar{L}/\bar{T})v^*}{d\bar{L}z^*} +$$

$$\rho^* \left(\bar{L}/\bar{T} \right) \frac{v^*}{A^* \bar{L}^2} \frac{d\bar{L}^2 A^*}{d\bar{L}z^*} = 0 \qquad (51)$$

$$\rho^* \left(\frac{d(\bar{L}/\bar{T})v^*}{d\bar{T}t^*} + \bar{L}/\bar{T}\, v^* \frac{d(\bar{L}/\bar{T})}{d\bar{L}z^*} v^* \right) + \frac{dp^*}{d\bar{L}z^*}$$

$$+ (f/8)\, \rho^*\, v^{*2} \frac{\bar{L}^2}{\bar{T}^2} \frac{\bar{L}p^*}{\bar{L}^2 A^*} + \rho^* \frac{\bar{L}}{\bar{T}^2} g^* \cos\theta = 0 \qquad (52)$$

$$\rho^* \left(\frac{dh^*}{d\bar{T}t^*} + \bar{L}/\bar{T}\, v^* \frac{dh^*}{d\bar{L}z^*} \right) - \left(\frac{dp^*}{d\bar{T}t^*} + \bar{L}/\bar{T}\, v^* \frac{dp^*}{d\bar{L}z^*} \right)$$

$$-\bar{L}/\bar{T}\, v^* (f/8\, \rho^* v^{*2})(\bar{L}^2/\bar{T}^2) \frac{\bar{L}p^*}{\bar{L}^2 A^{*2}} - \bar{Q}Q^* = 0 \qquad (53)$$

Simplifying we get the following conservation equations :

Mass

$$\frac{d\rho^*}{dt^*} + v^* \frac{d\rho^*}{dz^*} + \rho^* \frac{dv^*}{dz^*} + \frac{\rho^* v^*}{A^*} \frac{dA^*}{dz^*} = 0 \qquad (54)$$

Momentum

$$\rho^* \left(\frac{dv^*}{dt^*} + v^* \frac{dv^*}{dz^*} \right) + (\bar{T}/\bar{L})^2 \frac{dp^*}{dz^*} +$$

$$\left(k\, \rho^* v^{*2} \right) P^*/A^* + \rho^* g^* \cos\theta = 0 \qquad (55)$$

Energy

$$\rho^* \left(\frac{dh^*}{dt^*} + v^* \frac{dh^*}{dz^*} \right) - \left(\frac{dp^*}{dt^*} + v^* \frac{dp^*}{dz^*} \right) +$$

$$\tau_W^*\, v^*\, P^*/A^* (\bar{L}/\bar{T})^2 - \bar{Q}\, \bar{T}\, Q^* = 0 \qquad (56)$$

The two sets of the conservation equations for the linearly scaled facility (equations 1, 2 and 3) and for the Candu (equations 54, 55 and 56) are identical and therefore the dynamic behaviour of the two systems is equivalent if :

$$\bar{L} / \bar{T} = 1 \qquad (57)$$

and

$$\bar{Q} \cdot \bar{T} = 1 \qquad (58)$$

Equation (57) implies that the time scaling factor $\bar{T}$ and the geometric scaling factor $\bar{L}$ are equal. Since the geometric and time scaling factors must be identical, the acceleration is scaled down by $1/\bar{L}$ while the velocity scaling factor remains unity.

Equation (58) implies that the ratio of the heat generation rate per unit volume between the facility and the Candu, $\bar{Q}$, is equal to the inverse of either the time scaling factor $\bar{T}$ or geometric scaling factor $\bar{L}$. Therefore, once the geometric scaling down by a factor $\bar{L}$ is complete, the Facility can be operated at $1/\bar{L}^2$ times the power under comparable conditions for the Candu. That is an advantage of the linear scaling. But then the gravity driven flows would be distorted, because the acceleration due to gravity in the vertical sections cannot be simulated as g/L.

2. Scaling Laws for Predominant Two Phase Flow

Thermosyphoning flow transients under Candu decay power are expected to be slow. That means that relative changes in phase hydraulic nonequilibrium are expected to be small. One is interested in predicting the behaviour of the fluid as a whole, ascertaining its heat transport system capability and adequacy of driving forces to transport the fluid, rather than the behaviour of each of the phases. There are exceptions, where the vapor and the liquid behave quite differently from each other. For example there are regions of fluid holdup in steam generators following reflux condensation and regions of possible flow stratification in horizontal pipes. To identify and scale such regions separate effects tests may be needed.

Scaling laws for two phase flow systems based on drift flux model have been developed and discussed by Ishii and Jones (Reference 12), Ishii and Zuber (Reference 13), Kocamustafaogullari and Ishii (Reference 7), Ishii and Katoaka (Reference 14).

The following analysis is based upon the above references and includes the recommendation of reference 7.

2.1 Scaling Parameters

The following dimensionless groups are identified. For complete similarity they should be all equal in the model and the reactor. Subscript 'o' refers to the reference dimension of the core and subscript 'i' refers to the parameters of the ith section of the flow loop.

2.1.1 Density Ratio Group

$$N_\rho = \frac{\rho_g}{\rho_L} \qquad (59)$$

so that $$1 - N_\rho = \frac{\rho_L - \rho_g}{\rho_L} \qquad (60)$$

This group scales the dynamic effect of pressure on flow density and hence scales the void fraction and quality in the model and reactor. For light and heavy waters, this ratio is approximately constant.

Table IV shows the value of this group. Since the thermosyphoning facility will be operated at pressure typical of a Candu, the only distortion is from inherent density ifferences between heavy and light waters. They do not exceed 10% as shown in Table IV.

2.1.2 Phase Change Number

This is defined such that :

$$\frac{N_{ph}}{(1 - N_\rho)} = \frac{Q_{Total}}{\dot{m} \cdot H_{fg}} = \frac{4\ q_o'''\ l_o}{D\ v_o\ h_{fg}\ \rho_L} \qquad (61)$$

where conduction depth equals the radius of the fuel pin.

This dimensionless similarity parameter expresses the capacity of the heat source to convert all of the flow to vapor if it was saturated liquid. So it scales the changes in phase due to heat transfer.

2.1.3 Subcooling Number

This parameter defines the degree of subcooling and is mainly determined by excess cooling in the steam generators. As one of the most important scaling parameters it takes into account time lag effects in the liquid region due to subcooling of the fluid entering the heated section.

$$N_{sub}/(1-N_\rho) = \Delta H_{sub}/H_{fg} = (H_{Ls} - H)/H_{fg} \qquad (62)$$

so that

$$(N_{ph} - N_{sub})/(1-N_\rho) = (Q_{Total} - Q_{Ls})/(\dot{m}\ H_{fg})$$

where Q_{Ls} = heat to raise the liquid to saturation.

The Phase Change Number and the Subcooling Number are then related by :

$$N_{ph} - N_{sub} = (\Delta\rho/\rho g)\ X_e \qquad (63)$$

2.1.4 Friction Number

This dimensionless similarity parameter quantifies the frictional losses.

$$N_f = (fl/D)\ \Phi_{Lo}^2\ (A_o/A_i)^2 \qquad (64)$$

where Φ_{Lo}^2 = two phase multiplier

$$= (1+(u_{fg}/u_L)\langle x\rangle)\ (\ (\mu_L/\mu_g)\langle x\rangle+(1-\langle x\rangle)\ )^{-0.25}$$

$$= (\ 1 + x\,\Delta\rho/\rho g\ )\ /\ (\ 1 + x\ \mu/\mu_g)^{0.25} \qquad (65)$$

2.1.5 Orifice Number

Like the friction number, this parameter quantifies the scaling of pressure losses (in orifices) and suggests that the orifice coefficient (and f.l/D in the friction number) can be varied in the model only if the area ratio A_o/A_i is varied according to :

$$N_o = K\ .\ \Phi_{Lo}^2\ (A_o/A_i)^2 \qquad (66)$$

2.1.6 Heat Source Number

This dimensionless parameter is the ratio of total core heat, Q(Total), to that required to bring the subcooled liquid to saturation, Q .

$$Q_{si} = (\ q"'\ \pi D\ l\ C_p)\ /\ (\ (\pi D^2/4)\ v_o\ \rho\ \Delta T\ C_p)$$

$$= (\ q"'\ l\ )\ /\ (\ v_o\ \Delta H_{sub}\ ) \qquad (67)$$

2.1.7 Critical Heat Flux (CHF) Number

It denotes the ratio of heat flux required for dryout under given fluid conditions to the core heat flux at that time.

$$N_{CHF} = (\ q_{CHF}"'/\ \delta\ q_o"'\ ) \qquad (68)$$

2.1.8 Froude Number

$$N_{Fr} = v_o^2\ /\ (\ g\ \ l_o\ \langle\alpha\rangle_o)\ (\ 1\ -\ N_\rho) \qquad (69)$$

2.1.9 Void-Quality Relation (Drift Flux Number)

This dimensionless similarity parameter characterises the flow pattern and includes the effect of slip between the phases.

$$N_d = v_{gj}\ /\ v_o \qquad (70)$$

The drift velocity correlation (reference 15) gives :

$$v_{gJ} = .2(1-(\rho_g/\rho_L)^{1/2})j+1.4(\sigma\ g\ \Delta\rho/\rho_L^2)^{1/4} \qquad (71)$$

where volumetric flux, j, in the heated section is given by :

$$j = (1 + x (\Delta\rho/\rho_g)) v_o \qquad (72)$$

so that

$$N_d = .2 (1-(\rho_g/\rho_L)^{1/2}) (1+x(\Delta\rho/\rho_L)) + 1.4 / v_o (\sigma g \Delta\rho/\rho^2)^{1/4} \qquad (73)$$

The first term in the above equation represents the distribution controlled slip while the second term represents the local slip. For most cases the first term predominates and the local slip can be neglected. Equation (76) can be replaced by any other suitable void quality relationship.

$$\alpha = \alpha (x,\rho,\mu,G,P,etc..) \qquad (74)$$

2.1.10 Characteristic Time Ratio Group

This parameter defines the ratio of heat conduction time to fluid travel time in the core.

$$Ti = (\alpha/\delta^2) . (l_o/v_o) \qquad (75)$$

2.1.11 Geometric Similarity Group for Lenyth

$$N_L = l_i / l_o \qquad (76)$$

This group defines the ratio of flow length of a given network segment to the length of the heated section in the core.

2.1.12 Geometric Similarity Group for Areas

$$N_A = A_i / A_o \qquad (77)$$

This parameter defines the ratio of flow area in a given segment to the flow area in the core.

2.2 Scaling Laws

In order for the model to dynamically simulate the reactor, the similarity parameters 1 through 12 must be equal both for the thermosyphoniny facility and the reactor. The degree of correspondence, even if equivalence of all twelve parameters is met, would, of course, be limited by the approximation inherent to the governing equations of the parent model.

It is recognised that precise scaling of two-phase flows is practically impossible over the range of anticipated pressures and temperatures. Let us assume that light water adequately models the behaviour of heavy water and that the solid thermal characteristics of the nuclear reactor core can be scaled and simulated with indirect electrically heated rods. This permits us to factor out the fuel and fluid properties (for the same operating pressure) and the scaliny criteria becomes more manageable.

As in the previous section, let us define a ratio parameter, X_R, as the ratio of the value of that parameter for the thermosyphoning facility to that in the reactor.

$$X_R = X_F / X_C \tag{78}$$

The similarity criteria expressed as ratios becomes :

$$(N_{ph})_R = (\delta_R\, q_R''' \, l_R)/(D_R\, v_R) = 1 \tag{79}$$

$$(N_{Fr})_R = v_R^2 / (l_R \langle\alpha\rangle_R) = 1 \tag{80}$$

$$(N_f)_R = (fl/D)_R\, (A_o/A_i)_R^2 = 1 \tag{81}$$

$$(N_o)_R = K_R\, (A_o/A_i)_R^2 = 1 \tag{82}$$

$$(T)_R = l_R / (\delta_R^2\, v_R) = 1 \tag{83}$$

$$(Q_{si})_R = (q_R''' \, l_R) / (v_R\, H_{subR}) = 1 \tag{84}$$

$$(\Delta Hsub)_R = 1 \tag{85}$$

$$(N_q)_R = (q''_{CHF})_R / (\delta_R (q''')_R = 1 \tag{86}$$

$$(N_d)_R = (v_{gj})_R / v_R = 1 \tag{87}$$

or

$$(N_d)_R = \alpha_R = 1$$

Equation 87 is satisfied for v_R=1 if both term of Equation 73 are of the same order of magnitude. In most cases, however, the local slip does not appreciably distort the void-quality relationship. Therefore, we can assume that, at this stage, we do not have to impose the restriction of equality of flow velocities and the equation 87 is automatically satisfied (by equality of fluid properties).

For the same subcooling, from Equations 63, 79 and 85, we get :

$$x_R = 1 \tag{88}$$

Therefore, the void similarity also holds :

$$\alpha_R = 1 \tag{89}$$

From Equation 79, we get

$$(\delta_R / D_R)\, ((q_R''' . l_R)/(v_R) = 1 \tag{90}$$

From Equations 80 and 89, we get

$$v_R^2 / l_R = 1 \tag{91}$$

From Equation 86, we get

$$l_R / (\delta_R^2 \cdot v_R) = 1 \qquad (92)$$

From Equations 84 and 85, we get

$$q'''_R \, l_R / v_R = 1 \qquad (93)$$

Equations 90 through 93 are four equations with 5 unknowns. We can express the four variables δ_R, D_R, v_R and q_R''' in terms of the fifth l_R.

In the physical scaling down of the prototype the length ratio is a convenient variable. From Equation 90 through 93 we get with l_R as the independent variable :

$$v_R = (l_R)^{1/2} \qquad (94)$$

$$\delta_R = (l_R)^{1/4} \qquad (95)$$

$$q_R''' = (l_R)^{-1/2} \qquad (96)$$

$$D_R = (l_R)^{1/4} \qquad (97)$$

With these scaling boundaries real time simulation cannot be obtained. The time scale is reduced and the events are accelerated in the model.

$$t_R = \dot{l}_R / v_R = (l_R)^{1/2} \qquad (98)$$

Equation 93 implies that the power per unit volume to the model should be increased for $l_R < 1$.

The scaling criteria for single phase scaling were obtained earlier. From equations 17, 18 and 23 we get :

$$v_R = l_R = q'''_R \qquad (99)$$

and

$$t_R = 1 \qquad (100)$$

The single phase and two phase equations are identically satisfied for $l_R = 1$.

3. Scaling of Fluid Properties

Historically light water has been used as the modelling fluid both in CANDU safety analysis and code verification experiments. Most, if not all, pressure drop and heat transfer correlations are based on light water and offer industrial fluid data. There is a need to verify the maximum deviation of D2O behaviour from H2O behaviour for some basic heat transfer modes. In general, it is assumed that the hydrodynamics for both D2O and H2O are similar.

3.1 Single Phase Forced Convection

The most important physical property that controls heat removal by a fluid is its thermal conductivity. For the same heat flux from a surface and the same difference in temperature between the surface and the fluid, the Nusselt numbers for two fluids must vary inversely as the thermal conductivities of the fluids.

$$q''_F / q''_C = (h\Delta T)_F / (h\Delta T)_C = (Nu\ k\Delta T)_F / (Nu\ k\Delta T)_C = 1$$

or

$$Nu_C/Nu_F = k_C/k_F = \frac{\text{Thermal Conductivity of D20}}{\text{Thermal Conductivity of H20}}$$

The ratio of Nusselt numbers for liquid heavy and light waters at saturation is given below. The effect of pressure on thermal conductivities is smaller than that of temperature. At constant pressure the thermal conductivities of both fluids increases with temperature up to 130 °C. Thereafter they decrease with temperature. Property data are derived from references 16 and 17.

$$\text{Ratio} = Nu_F/Nu_C = K_{D20}/K_{H20}$$

Pressure (psia)	Ratio
20	.9426
50	.9296
100	.9177
200	.9047
500	.8927
1000	.8751

For the same flow velocity in ducts of identical diameters and heat fluxes, the ratio of temperature rises in the model and reactor can be expressed using Dittus Boelter correlation as :

$$T_F/T_C = (\nu^{.8} P_r^{.4} k)_{D20} / (\nu^{.8} P_r^{.4} k)_{H20}$$

The numerical values of this ratio at saturation temperatures given below are :

Temperature °C	Ratio
20	1.028
60	1.011
100	1.033
200	1.038

3.2 Single Phase Natural Circulation

In horizontal tubes, free convection sets up secondary flows (in fuel bundles and other horizontal sections) that help the convection process. In vertical tubes the effect of free convection depends upon the flow direction and wether the fluid is heated or cooled. For fluid heating with upward flow free convection aids forced convection and the resultant heat transfer coefficient is higher than the pure forced-convection heat transfer coefficient. The same is true for fluid cooling with downward flow. Similarly for fluid heating with downward flow (or cooling with upward flow) free convection acts against forced convection and a lower heat transfer coefficient results.

Free convection from fuel rods can be modelled as if from horizontal cylinders. In this case the heat transfer coefficient (or Nusselt Number) is a function of Grashof Number (ratio of buoyancy to shear forces) and Prandtl Number (ratio of momentum to thermal diffusion). The exact relationship is subject to a lot of empiricism and depends upon the magnitude of Grashof and Prandtl Numbers. The general form, based upon numerous experiments, is :

$$Nu = c \left(G_r P_r \right)^n$$

where

$$G_r = (\beta g \rho^2 \left(T_W - T_\infty \right) D^3) / \mu^2 \text{ and}$$

$$P_r = \mu C_p / k$$

c,n = functions of magnitute of $(G_r.P_r)$ for $10^4 < Gr.Pr < 10^9$

$$c = 0.53 \; ; \; n = 0.25$$

$$Nu = c \left(G_r P_r \right)^n$$

$$= c \left(G_r' P_r \right)^n T^n$$

where

$$G_r' = G_r / (\Delta T.D^3) = (g\beta/\nu^2)$$

$$N_C / N_F = (G_r'P_r)C^n / (G_r'P_r)_F^n$$

Also,

$$\Delta T = (Nu \, (K/D) \, (1/q"))^{-1}$$

$$\Delta T_C / \Delta T_F = (((Gr'Pr)^n K)_F / ((Gr'Pr)^n K)_C)^{1/(n+1)}$$

for $n = 1/4$, $\Delta T_C / \Delta T_F =$

$$((Gr'Pr)^{1/5} K^{4/5})_F / ((Gr'Pr)^{1/5} K^{4/5})_C$$

The numerical values of the ratio of wall superheats at saturation is computed using property values from references 16 and 17 as :

Temperature °C	Ratio ($\Delta T_C / \Delta T_F$)
20	1.0165
60	1.0215
100	1.0280
200	1.0540

4. Conclusions and Recommendations

Conclusions

Three kinds of scaling laws have been investigated.

i. Pure linear scaling would distort geometry. Linear scaling preserving area ratios is acceptable for subcooled portions and other one phase phenomena. For gravity induced phenomena it requires an adjustment of acceleration due to gravity. this scaling also results in reduced time scales.
ii. Volumetric scaling including power to volume scaling and break area to volume scaling have been extensively used but are not developed or mathematically justified for non homogeneous two phase conditions.
iii. Two phase scaling based upon drift flux formulation has been suggested for reactor simulation over a range of phase conditions.

This third method has sound mathematical bases and is recommended.

Recommendations

i. Use of light water will not produce significant distorsions.
ii. Diameter of major heat transfer surfaces should be preserved.
iii. Following an independent decision on the total number of channels in the simulated core, the geometry should be scaled following the scaling methodology of Kocamustafaogullari and Ishii, that is based upon the drift flux formulation of two phase equations.
iv. The ideal scaling factor is unity. This would preserve flow length, system height, fluid transit time and the driving force for the thermosyphoning fluid. Both single and two phase criteria are simultaneously met.
v. In order to investigate the thermosyphoning phenomena qualitatively, a reduced length facility under similar pressure and thermal conditions can be designed.
vi. Basic geometric characteristics of the fluid paths should be preserved: the geometry of the feeder, endfittings, core and piping should be maintained as well as possible.

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F. NOMENCLATURE

The following symbols have been used throughout the report.

A	Flow area
A_s	Heat transfer area
C_p	Fluid heat capacity
D	Diameter
f	Friction factor
F_r	Froude number
g	Acceleration due to gravity
G	Volumetric flow rate
G_r	Grashoff number
h	Enthalpy
$h_{i,o}$	Convective heat transfer coefficient
H_{fg}	Latent heat
j	Total volumetric flux
k	Thermal conductivity
K	Orifice coefficient
l	Length
L	Total length
N_d	Drift flux number
N_f	Friction number
N_{Fr}	Froude Number
N_o	Orifice number
N_{ph}	Phase change number
N_{sub}	Subcooling number

Nu	Nusselt Number
P	Pressure
p	Perimeter
q''	Heat flux
q'''	Volumetric heat generation rate
Q	Total power
r	Radius
t	Time
T	Temperature
v	velocity
V	Volume
v_{gj}	Drift Velocity
W	Mass flow rate
x	Quality
	Void fraction
	Thermal expansion foefficient
	Conduction thickness
ΔH_{sub}	Subcooling
ΔT	$T_W - T_L$
$\Delta\rho$	Liquid-vapor density difference
ρ	Density
σ	Surface tension
Σk	Sum of minor (form) losses
μ	Dynamic viscosity
ν	Kinematic viscosity
sf	Linear scaling factor
θ_τ	Angle to vertical shear stress

Subscripts

c	Core
C	Candu
f	Liquid
F	Thermosyphoning Facility
g	Vapor
L	Loss
o	External, reference scale
R	Model to reactor ratio
w	Wall

Superscripts

*	Candu parameter
+	Non-dimensional

Table 1

P/ρh for H20 and D20 at 0.1 MPa

Quality	D20 P/ρh	H20 P/ρh	Error (%)
0.0	.000230	.000250	8.7
0.1	.024941	.026480	6.2
0.2	.037225	.039080	5.0
0.3	.044572	.046483	4.3
0.4	.049461	.051354	3.8
0.5	.052948	.054803	3.5
0.6	.055561	.057373	3.3
0.7	.057592	.059362	3.1
0.8	.059216	.060948	2.9
0.9	.060544	.062241	2.8
1.0	.061650	.063315	2.7

Table 2

P/ρh for H20 and D20 at 0.2 MPa

Quality	D20 P/ρh	H20 P/ρh	Error (%)
0.0	.000387	.000420	8.6
0.1	.023213	.024700	6.4
0.2	.035783	.037666	5.3
0.3	.043742	.045731	4.5
0.4	.049233	.051233	4.1
0.5	.053251	.055226	3.7
0.6	.056317	.058256	3.4
0.7	.058735	.060633	3.2
0.8	.060690	.062549	3.1
0.9	.062304	.064125	2.9
1.0	.063658	.065445	2.8

Table 3

P/ρh for H20 and D20 at 0.3 MPa

Quality	D20 P/ρh	H20 P/ρh	Error (%)
0.0	.000529	.000573	8.3
0.1	.022287	.023737	6.5
0.2	.034931	.036818	5.4
0.3	.043195	.045223	4.7
0.4	.049020	.051079	4.2
0.5	.053346	.055392	3.8
0.6	.056686	.058702	3.6
0.7	.059343	.061322	3.3
0.8	.061506	.063448	3.2
0.9	.063303	.065207	3.0
1.0	.064817	.066686	2.9

Table 4

P/ρh for H2O and D2O at 0.4 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.000662	.000717	8.3
0.1	.021665	.023090	6.6
0.2	.034316	.036206	5.5
0.3	.042771	.044826	4.8
0.4	.048820	.050923	4.3
0.5	.053362	.055464	3.9
0.6	.056898	.058976	3.7
0.7	.059729	.061774	3.4
0.8	.062047	.064056	3.2
0.9	.063979	.065952	3.1
1.0	.065615	.067553	3.0

Table 5

P/ρh for H2O and D2O at 0.5 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.000789	.000854	8.1
0.1	.021203	.022603	6.6
0.2	.033833	.035716	5.6
0.3	.042417	.044484	4.9
0.4	.048632	.050760	4.4
0.5	.053339	.055474	4.0
0.6	.057028	.059144	3.7
0.7	.059997	.062084	3.5
0.8	.062437	.064490	3.3
0.9	.064479	.066497	3.1
1.0	.066213	.068196	3.0

Table 6

P/ρh for H2O and D2O at 1 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.001373	.001477	7.6
0.1	.019889	.021215	6.7
0.2	.032275	.034129	5.7
0.3	.041143	.043236	5.1
0.4	.047805	.050004	4.6
0.5	.052993	.055231	4.2
0.6	.057148	.059389	3.9
0.7	.060550	.062777	3.7
0.8	.063388	.067962	3.5
0.9	.065790	.067962	3.3
1.0	.067850	.069990	3.2

Table 7

P/ρh for H2O and D2O at 2 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.002415	.002590	7.2
0.1	.018816	.020080	6.7
0.2	.030617	.032430	5.9
0.3	.039515	.041616	5.3
0.4	.046463	.058716	4.8
0.5	.052040	.054368	4.5
0.6	.056615	.058974	3.9
0.7	.060435	.062800	3.9
0.8	.063673	.066029	3.5
0.9	.066454	.068789	3.5
1.0	.068866	.071177	3.4

Table 8

P/ρh for H2O and D2O at 3 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.002415	.003621	7.0
0.1	.018816	.019604	6.7
0.2	.030617	.031390	6.0
0.3	.039515	.040441	5.5
0.4	.046463	.047608	5.0
0.5	.052040	.053425	4.6
0.6	.056615	.058241	4.3
0.7	.060435	.062293	4.1
0.8	.063673	.065750	3.9
0.9	.066454	.068734	3.7
1.0	.068866	.071336	3.5

Table 9

P/ρh for H2O and D2O at 4 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.004316	.004606	6.7
0.1	.018181	.019400	6.7
0.2	.028886	.030648	6.1
0.3	.037400	.039488	5.6
0.4	.044335	.046619	5.2
0.5	.050091	.052492	4.8
0.6	.054947	.057414	4.5
0.7	.059097	.061598	4.2
0.8	.062686	.065199	4.0
0.9	.065819	.068331	3.8
1.0	.068579	.071079	3.6

Table 10

P/ρh for H2O and D2O at 5 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.005228	.005571	6.6
0.1	.018134	.019349	6.7
0.2	.028329	.030079	6.2
0.3	.036586	.038670	5.7
0.4	.043410	.045705	5.3
0.5	.049143	.051571	4.9
0.6	.054029	.056537	4.6
0.7	.058241	.060796	4.4
0.8	.061911	.064488	4.2
0.9	.065136	.067720	4.0
1.0	.067993	.070572	3.8

Table 11

P/ρh for H2O and D2O at 6 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.006128	.006522	6.4
0.1	.018187	.019400	6.7
0.2	.027895	.029629	6.2
0.3	.035878	.037950	5.8
0.4	.042558	.044852	5.4
0.5	.048230	.050668	5.1
0.6	.053107	.055637	4.8
0.7	.057344	.059931	4.5
0.8	.061060	.063679	4.3
0.9	.064345	.066979	4.1
1.0	.067271	.069906	3.9

Table 12

P/ρh for H2O and D2O at 7 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.007026	.007564	6.2
0.1	.018304	.019520	6.6
0.2	.027533	.029262	6.3
0.3	.035224	.037298	5.9
0.4	.041732	.044039	5.5
0.5	.047310	.049775	5.2
0.6	.052145	.054716	4.9
0.7	.056376	.059016	4.7
0.8	.060108	.062792	4.5
0.9	.063427	.066134	4.3
1.0	.066396	.069114	4.1

Table 13

P/ρh for H2O and D2O at 8 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.007924	.008409	6.1
0.1	.018485	.019702	6.6
0.2	.027251	.028967	6.3
0.3	.034646	.036705	5.9
0.4	.040967	.043264	5.6
0.5	.046432	.048896	5.3
0.6	.051205	.053783	5.0
0.7	.055408	.058064	4.8
0.8	.059139	.061846	4.6
0.9	.062472	.065210	4.4
1.0	.065468	.068223	4.2

Table 14

P/ρh for H2O and D2O at 9 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.008829	.009361	6.0
0.1	.018703	.019930	6.6
0.2	.027009	.028720	6.3
0.3	.034091	.036147	6.0
0.4	.040203	.042503	5.7
0.5	.045531	.048006	5.4
0.6	.050216	.052816	5.2
0.7	.054368	.057056	4.9
0.8	.058073	.060822	4.7
0.9	.061401	.064190	4.5
1.0	.064404	.067219	4.4

Table 15

P/ρh for H2O and D2O at 10 MPa

Quality	D2O P/ρh	H2O P/ρh	Error (%)
0.0	.009751	.010316	5.8
0.1	.019134	.020203	5.6
0.2	.027113	.028532	5.2
0.3	.033981	.035643	4.9
0.4	.039955	.041786	4.6
0.5	.045199	.047146	4.3
0.6	.049838	.051864	4.1
0.7	.053973	.056048	3.8
0.8	.057680	.059784	3.6
0.9	.061023	.063140	3.5
1.0	.064053	.066172	3.3

Table 16

Properties of Heavy Water at Saturation

Press MPa	Temp °C	VF m3/kg	VG	HF	HFG kJ/kg	HG
0.1	101.05	.0009412	1.52947	409.49	2071.4	2480.9
0.2	121.41	.0009568	.79885	494.14	2015.7	2509.8
0.3	134.56	.0009682	.54600	548.86	1978.2	2527.1
0.4	144.53	.0009776	.41654	590.40	1948.9	2539.3
0.5	152.66	.0009858	.33750	624.36	1924.2	2548.6
1.0	180.38	.0010173	.17474	741.20	1834.2	2575.4
2.0	212.51	.0010625	.08934	879.75	1714.9	2594.6
3.0	233.75	.0010989	.05971	974.14	1624.8	2598.9
4.0	250.07	.0011317	.04452	1048.78	1548.0	2596.7
5.0	263.51	.0011626	.03523	1112.00	1478.7	2590.7
6.0	275.03	.0011927	.02895	1167.75	1414.3	2582.1
7.0	285.16	.0012227	.02439	1218.25	1353.1	2571.4
8.0	294.24	.0012529	.02094	1264.90	1293.9	2558.8
9.0	302.49	.0012838	.01821	1308.63	1236.1	2544.7
10.	310.06	.0013125	.01621	1346.08	1184.6	2530.7

Table 17

Properties of Light Water at Saturation

Press MPa	Temp °C	VF m3/kg	VG	HF	HFG kJ/kg	HG
0.1	99.63	.001043	1.6940	417.46	2258.0	2675.5
0.2	120.23	.001061	.8857	504.70	2201.9	2706.7
0.3	133.55	.001073	.6058	561.47	2163.8	2725.3
0.4	143.63	.001084	.4625	604.31	1949.3	2737.6
0.5	151.86	.001093	.3749	640.23	2108.5	2748.7
1.0	179.91	.001127	.19444	762.81	2015.3	2778.1
2.0	212.42	.001177	.09963	908.79	1890.7	2799.5
3.0	233.90	.001217	.06668	1008.42	1795.7	2804.2
4.0	270.40	.001252	.04978	1087.31	1714.1	2801.4
5.0	263.99	.001286	.03944	1154.23	1640.1	2794.3
6.0	275.64	.001319	.03244	1213.35	1571.0	2784.3
7.0	285.88	.001351	.02737	1267.00	1505.1	2772.1
8.0	295.06	.001384	.02352	1316.64	1441.3	2758.0
9.0	303.40	.001418	.02048	1363.26	1378.9	2742.1
10.	311.06	.001452	.01803	1406.56	1317.1	2724.7

Table 16

Properties of Heavy Water at Saturation

Press MPa	Temp °C	VF m^3/kg	VG	HF	HFG kJ/kg	HG
0.1	101.05	.0009412	1.52947	409.49	2071.4	2480.9
0.2	121.41	.0009568	.79885	494.14	2015.7	2509.8
0.3	134.56	.0009682	.54600	548.86	1978.2	2527.1
0.4	144.53	.0009776	.41654	590.40	1948.9	2539.3
0.5	152.66	.0009858	.33750	624.36	1924.2	2548.6
1.0	180.38	.0010173	.17474	741.20	1834.2	2575.4
2.0	212.51	.0010625	.08934	879.75	1714.9	2594.6
3.0	233.75	.0010989	.05971	974.14	1624.8	2598.9
4.0	250.07	.0011317	.04452	1048.78	1548.0	2596.7
5.0	263.51	.0011626	.03523	1112.00	1478.7	2590.7
6.0	275.03	.0011927	.02895	1167.75	1414.3	2582.1
7.0	285.16	.0012227	.02439	1218.25	1353.1	2571.4
8.0	294.24	.0012529	.02094	1264.90	1293.9	2558.8
9.0	302.49	.0012838	.01821	1308.63	1236.1	2544.7
10.	310.06	.0013125	.01621	1346.08	1184.6	2530.7

Table 17

Properties of Light Water at Saturation

Press MPa	Temp °C	VF m^3/kg	VG	HF	HFG kJ/kg	HG
0.1	99.63	.001043	1.6940	417.46	2258.0	2675.5
0.2	120.23	.001061	.8857	504.70	2201.9	2706.7
0.3	133.55	.001073	.6058	561.47	2163.8	2725.3
0.4	143.63	.001084	.4625	604.31	1949.3	2737.6
0.5	151.86	.001093	.3749	640.23	2108.5	2748.7
1.0	179.91	.001127	.19444	762.81	2015.3	2778.1
2.0	212.42	.001177	.09963	908.79	1890.7	2799.5
3.0	233.90	.001217	.06668	1008.42	1795.7	2804.2
4.0	270.40	.001252	.04978	1087.31	1714.1	2801.4
5.0	263.99	.001286	.03944	1154.23	1640.1	2794.3
6.0	275.64	.001319	.03244	1213.35	1571.0	2784.3
7.0	285.88	.001351	.02737	1267.00	1505.1	2772.1
8.0	295.06	.001384	.02352	1316.64	1441.3	2758.0
9.0	303.40	.001418	.02048	1363.26	1378.9	2742.1
10.	311.06	.001452	.01803	1406.56	1317.1	2724.7

Table 18

Summary of Similitude Study

($F^3 = V_{reactor} / V_{rig}$)

		Time Preserving Case I (Model)	Time Reducing Case II (Model)
t	- Blowdown time	1	$1/F$
AB	- Break area	$1/(F^3)$	$1/F^2$
Lc	- Core length	$1/(F^3)$	$1/F$
Ac	- Core flow area	$1/(F^3)^2$	$1/F^2$
V1	- Lower volume	$1/(F^3)$	$1/F^3$
V2	- Upper volume	$1/(F^3)$	$1/F^3$
M1	- Mass, lower volume	$1/(F^3)$	$1/F^3$
M2	- Mass, upper volume	$1/(F^3)$	$1/F^3$
K	- Core flow resistance	$(F^3)^2$	F^4
W	- Break and core flow rate	$1/(F^3)$	$1/F^2$
Q	- Core heat input	$1/(F^3)$	$1/F^2$
V1/V2	- Volume ratio	1	1
M1/M2	- Mass distribution	1	1
Lc/Ac	- Core length to area ratio	(F^3)	F
AB/V2	- Break area to volume ratio	1	F
AB/AC	- Break to flow area ratio	(F^3)	1
P1-P2	- Core pressure loading	Distorted $\neq 1$	Distorted $\neq 1$

SECTION 2

- CONCEPTUAL DESIGN -

A. INTRODUCTION

The purpose of the present section is to define the geometric data of the primary heat transport system of the thermosyphoning facility. A scaling methodology has been recommended previously and will be applied in the present task. The overall target of the feasibility study of the thermosyphoning rig is to design a facility that can give useful and relevent information on the behaviour of a Candu-600 in particular and on any Candu reactor in general, under conditions wherein forced circulation as the primary mode of heat removal is unavailable with or without a breach in the pressure boundary. The system of interest is the primary heat transport system. All other systems are required only as services or auxiliary systems and therefore the scaling of those systems need only be such as their boundary conditions with the scaled PHTS are properly scaled.

In addition to defining the conceptual design of the rig, a rationale on instrumentation has been developped and instrumentation locations have been defined.

Appendix S1 contains the listing of the computer programs used to define the geometric data of the thermosyphoning facility.

B. SCALING APPLICATION

1. Independent Design Decisions

Following the recommendation made in Section 1 (scaling) the basic scaling technique used is two phase scaling of the Candu 600 MWe reactor. The scaled down design is subject to the following independent design decisions.

1.1 Figure of Eight Loop

In order to faithfully duplicate a Candu 600 thermohydraulics under steady state and transient conditions a figure of eight loop has been chosen. Such a loop will preserve the pass to pass assymetries generated by the pressuriser and feed and bleed locations. In addition under a loss of coolant accident as a possible initial condition for thermosyphoning, the facility best reproduces the Candu conditions with a figure of eight loop. However, the relative effects of pass to pass assymetries are likely to be more pronounced with the number of channels, reduced from 95 per pass to a much smaller number.

1.2 Number of Channels

The number of channels required for the test facility has been determined by the following criteria:

- cost of the facility
- representativity

The 95 actual channels differ from each other by the following factors :

. channel power
. channel height
. feeder geometry
. header connection

Height is the only parameter which cannot be adjusted once the facility is built. It is also the parameter that is of paramount importance to the thermosyphoning phenomena that the facility is supposed to duplicate. A conceptual division of the core face into three different heights can be made. A larger subdivision, though theoretically desirable, is precluded by economic considerations. Thus we have chosen to consider the behaviour of three channels of widely different heights.

In order to take into account different feeder geometries for the same height one additional channel is required.

In order to segregate power effects from height and feeder geometry a fifth channel is required.

Therefore a minimum of five channels per pass are recommended and included in the conceptual design of the facility.

1.3 Channel Diameter

The diameter of the channel required for the facility has been determined by using the following criteria:

. cost of the facility
. representative behaviour

The cost of a full size channel can be high. If subchannel phenomena do not dictate the behaviour of the system under thermosyphoning conditions, and only relative magnitudes, distributions and locations of heat sinks and heat sources are important, then a reduced scale channel can be justified. The aim of the facility is to generate reproducible thermosyphoning behaviour characteristics. A correctly scaled system of heat sources and heat sinks, while preserving some subchannel effects, can be designed with about half the channel diameter. Therefore the diameter of the facility's channel has been chosen to be about half the full scale diameter.

It is desirable that the heat transfer surface diameters be preserved. Therefore the pins in the facility would have the same diameter as in the reactor. The only arrangement of pins that respects the fuel bundle subchannel geometry is shown in Figure 1.

Seven electrically heated (indirect heating) full channel length fuel pins with unheated ends will represent the Candu-600 fuel bundles.

1.4 Pressure

The void-quality relationship and flow regime transitions are pressure dependent. In order to avoid distorsions which can be unquantifiable, the maximum operating pressure of the facility will be similar to that of Candu-600 (inlet header pressure of 11.24 MPa).

1.5 Fluid

For obvious cost reasons the facility will be a light water facility. It has been shown in Section 1 that the energy and momentum transfer characteristics of light and heavy water are similar and for experimental conditions, difference between light water and heavy water properties is acceptable. In addition the thermohydraulic correlations employed to design and to evaluate the safety of all the Candu reactors, have traditionally been for ligth water and the extrapolation from light water to heavy water has produced no significant distorsions.

1.6 Heater Heat Flux

After a reactor shutdown the axial channel power distribution in a reactor is rather flat. In addition the variance from flat profile is spatially different and time dependent. Therefore no single non uniform flux distribution can adequately represent the core. Consequently the heater elements will have a constant heat flux. It also becomes a sound economic decision.

1.7 Steady State Power

The steady state power of the facility must be such as to generate the same enthalpy distribution as that in a Candu during pump rundown. The maximum channel power of the facility will be scaled down to the value dirived from the scaling analyses and on top of that scaling we will apply a somewhat arbitrary maximum power factor of about 10% to the scaled down power. In a Candu the power ramps down to 10% in a fraction of a second after reactor shutdown. During that time the system enthalpy distributions have not had an opportunity to change (the travel time around the loop is about 14 seconds and the steam generators for example will still deliver close to 100% of full power steam flow for another five to 10 seconds). If the proposed facility can maintain the steady state (100% power) systems conditions for only 10% power, a significant cost reduction can be achieved. This means that the facility will reproduce the Candu behaviour starting a fraction of a second after reactor shutdown. The justification lies in the fact that the thermosyphoning phenomena which are of interest are those that happen a few minutes after reactor shutdown a time at which the early "history" of the transient begins to be of minor importance.

1.8 Steam Generator Secondary Side

The U tube steam generators in a Candu are designed to provide a large thermal inertia in order to accomodate any main feedwater loss during operation. This thermal inertia is also very important during thermosyphoning. Therefore the steam generator will be scaled down for the facility full power scaling.

The steady state thermal hydraulic conditions in the primary heat transport system and the steam generator will be set up for low power levels by tuning the feedwater flows. The steam generator secondary side will be a closed loop.

1.9 Inlet and Outlet Headers

The headers may serve under thermosyphoning conditions as surge volumes that allow fluid accumulation and recirculation to other fuel channels. Inlet and outlet headers have been scaled according to a somewhat different rationale which accounts for its geometric and flow path characteristics. In particular volume scaling of the headers would require a small header and would not represent the phenomena that may take place during thermosyphoning transients under two phase conditions. It is the flow paths of the different flows that come out from the feeders that have to be scaled.

2. Description of the Facility

2.1 Basic Conceptual Design

The facility consist of the following main process systems :

- A Primary Heat Transport System as shown in Figure 2 containing :

. 2 pass figure of eight loop
. 5 channels per pass
. 7 heating elements per channel
. 2 pumps
. 2 steam generators
. 2 outlet headers
. 2 inlet headers
. 10 inlet feeders
. 10 outlet feeders
. An outlet header to outlet header interconnect

- A Pressuriser as shown in Figure 3

- A Feed and Bleed System as shown in Figure 4

- An Emergency Water Supply (EWS) System as shown in Figure 5.

- A ShutDown Cooling System (SDCS) as shown in Figure 6.

- A three stage Emergency Core Cooling System (ECCS) as shown in Figure 7.

- A Secondary side feedwater system as shown in Figure 8.

- A Secondary side heat sink as shown in Figure 9.

In addition the facility will have the following support systems:

- Instrumentation system (Figure 10)

- Control system (Figure 11)

- Data acquisition system (Figure 12)

- Personnel and facility safety systems (facility specific) (Figure 13)

- Data storage and display system (Figure 14)

- Water deareation system (Figure 15)

- Electrical power supply system (Figure 16)

Figure 17 gives a schematic of all the auxiliary systems of the facility.

2.2 Global Scaling Parameters

The overall scaling of the facility is governed by the following scaling decisions :

i) the 37 pin fuel bundle is replaced in the facility by a 7 pin electrically heated bundle with uniform heat flux.
ii) the fuel pin diameter is preserved. This helps reduce distorsions in bubble growth dynamics.
iii) the flow area for each unit cell is preserved. That means that the fuel pin and the electrically heated rod, beiny of the same diameter, have identical associated flow areas.
iv) two phase scaliny laws as discussed in Section 1 are employed.

2.3 Scaling of the Core

The reactor core is the object of the primary sacling decision. That decision defines the scaling of the rest of the PHTS.

The following analysis is performed to determine core geometry and to obtain, by application of the governing equations, the major system scaling parameters.

The flow area per unit cell in the Candu bundle is given by :

$$F_c = \frac{(Pi)}{4} \times \frac{D_c^2 - N_c\, d_c^2}{N_c}$$

In the above and the following discussion, the subscripts c and f stand for Candu and the facility respectively, and :

N = number of fuel pins or heater rods
D = diameter of the pressure tube
d = diameter of the fuel pin or heater rod
F = unit cell flow area
A = cross section area of the pressure tube
a = available flow area
DH = hydraulic diameter

$$DH_c = \frac{4 * \text{flow area}}{\text{wetted perimeter}} = \frac{(D_c^2 - N_c\, d_c^2)}{(D_c + N_c\, d_c)}$$

for D_c = 103.4 mm, N_c = 37 and d_c = 13.12 mm:

F_c = 91.75 mm^2 and DH_c = 7.341 mm.

For N_f = 7 and d_f = 13.12,

$D_f = (4/(Pi)\ F_c\ N_f + N_f\ d_f^2)^{1/2}$ = 44.97 mm

$DH_f = (D_f^2 - N_f.d_f^2\ ) / (D_f + N_f.d_f)$ = 5.977 mm

The area ratio between the facility and the Candu is equal to the number of pins ratio 7/37.

Therefore we have channel area ratio = 7/37

Unit cell hydraulic diameter ratio = 5.98/7.34 = 0.814

By Ishii's formulation (see Section 1) of two phase scaling laws we obtain :

Length ratio : $l_R = d_R^4 = (0.814)^4 = .44$

Volume ratio : $V_R = a_R\ l_R = 7/37 * .44 = .083$

Power density ratio : $q_R'''' = l_R^{-.5} = 1.508$

Total power ratio : $Q_R = q_R''''\ V_R = .1254$

Time ratio : $t_R = l_R^{.5} = .66$ (acceler. events)

The length ratio is determined by an assumption of equal fluid flow areas around the fuel elements in both the facility and the Candu. For ease of design and layout purposes an even length ratio of 0.5 is chosen. The analysis is redone, to verify the unit cells have similar flow areas.

Hydraulic diameter ratio :

$$d_R = l_R^{0.25} = 1/2^{0.25} = 0.8409$$

The hydraulic diameter of the unit cell in the facility fuel bundle is given by :

$$DH_f = d_R \, DH_c = 0.8409 * 7.341 = 6.173 \text{ mm}$$

The internal diameter of the test section pressure tube is then determined by solving :

$$DH_f = 6.173 = (D_f^2 - N_f.d_f^2) / (D_f + N_f.d_f)$$

for which we obtain D_f = 45.29 mm and the flow area per unit cell is :

$$(Pi)/4 \; (D_f^2 - N_f.d_c^2) / N_f = 94.98 \text{ mm}^2$$

The flow area per pin in the facility is about 103% (94.98 / 91.75) of the flow area per pin in a Candu. The real ratio will actually be determined by the size of the available pressure tubes for the facility which can have a diameter slightly smaller then the one calculated above.

The ratio of fluid flow areas between the facility and the Candu is the critical scaling parameter that will determine the size of all the facility's PHTS components. It is given by :

$$A_R = (D_f^2 - N_f d_c^2) / (D_c^2 - N_c d_c^2) = .1958$$

That number is about equal to the ratio of the number of fuel pins in the facility and the Candu (7 / 37).

The global scaling parameters which will be used below for the generation of the facility's dimensions are :

l_R	$= 1/2$	$= 0.5$	**Length ratio**
d_R	$= 1/2^{1/4}$	$= 0.8409$	**Diameter ratio**
A_R		$= 0.1958$	**Area ratio**
V_R	$= A_R * 1/2$	$= 0.0979$	**Volume ratio**
q_R'''	$= 1/2^{-1/2}$	$= 1.4142$	**Power density ratio**
Q_R	$= A_R * 1/2^{1/2}$	$= 0.1385$	**Power ratio**
t_R	$= 1/2^{1/2}$	$= 0.7071$	**Time ratio**

C. COMPONENT DATA

The scaled geometric parameters for the primary heat transport system of the proposed facility are derived and presented in this section. It is only the behaviour of the PHTS that the facility is required to characterise and duplicate. Therefore the systems auxilliary to the PHTS have not been scaled. The normalised performance characteristics of these systems will have to be respected in the actual facility. These systems have been designed schematically and their corresponding diagrams included in this report. Major design and scaling efforts were devoted towards quantifying the PHTS geometry and the results are presented below.

1. Primary Heat Transport System

Geometric scaling laws were applied to all PHTS components except the pumps. The flow versus head characteristics of the pumps was developed during the code based thermohydraulic analysis of the conceptual design of the facility. To avoid repetition, the scaling methodology is presented only if it differs from the one presented earlier. Otherwise only the main scaling operations are highlighted.

1.1 Channel

1.1.1 Core Section

length of heated section	2972	mm
number of pins per bundle	7	
pin O. D.	13.12	mm
pin hydraulic diameter	6.173	mm
pitch diameter of outer 6 elements	29.76	mm
pressure tube I. D.	45.29	mm
pressure tube flow area	94.98	mm^2
maximum channel power	100	kW

Based on the power scaling ratio of .1385 and on a maximum channel power of 6.5 MW in a Candu, the maximum channel power in the facility would be 900 kW. A 100 kW channel power would therefore represent 11% of full scale scaled power.

The ultimate maximum channel power in the facility will depend upon the availability of the heater rods. In any case 10% of the maximum scaled power is a minimum channel power that is required in the facility.

1.1.2 End Fitting Section

The end fitting length is scaled by the length scaling factor of 0.5. The annular flow geometry is scaled by the following pressure drop scaling criteria.

$(K + f\ l/D)_R\ (a_o/a_i)_R^2 = 1$ Where,

a_o = channel heated length flow area.

a_i = end fitting area.

K = distributed loss coefficient for entry end exit and line tube holes.

The end fitting flows are expected to be turbulent and the effect from Reynold's number should be small. The effect was however included to determine the hydraulic diameter (difference between the annulus OD and ID). Denoting by D the OD of the annulus and d the ID of the annulus, the governing equations can be reduced to:

$$\frac{K_f + (f_f L_f)/(D_f - d_f)}{K_c + (f_c L_c)/(D_c - d_c)} = ((D_f 2 - d_f 2)/(D_c 2 - d_c 2))^2 \; 1/A_R^2$$

with f = f (e/D,Re) using Wood's approximation of Colebrook equation.
and $Re_f = Re_c \cdot V_R \cdot (D_f - d_f) / (D_c - d_c)$

The above set of equations was numerically solved for a range of Reynold's numbers. For K varying from 0 to 6 and Re from 10**5 to 10**8 the annulus OD ranged from 68 to 66 mm. Taking into account the earlier onset of turbulence in the complex end fitting geometry as opposed to tubes for which the above friction factor formula is applicable, the annulus diameter was chosen to be 66.6 mm.

The scaled geometric data for the end fitting is presented below:

end fitting length	1115	mm
end fitting dead space	65	mm
annulus ID	55	mm
annulus OD	66.6	mm
shield plug length	279	mm
shield plug diameter	45	mm
diameter of the shield plug holes	13.25	mm

1.2 Feeders

In a typical Candu flow pass there are 95 pairs of feeders. They are all different from each other. The five pairs of feeders in the facility must represent the major geometrical characteristics of the Candu feeders.

The feeder geometry has been chosen such as to cover most types present in a Candu 600 (feeder-channel angle, horirontal length, vertical length).

The scaled dimensions of the facility's feeders have been obtained using the geometric information from the following feeders : C9, Q2, K9 and T11. The feeder type Q2 will be reproduced twice in the facility. This has been achieved by reducing the vertical run in Q2 to make it equal to the vertical run of K9.

All feeders will have the same number of bends as their counterparts in the Candu. In the final design stage the number of bends can be accomodated in order to match the desired resistance of a particular channel or to correct the resistance variation introduced by a feeder with a different diameter.

The feeders have been scaled according to the following formula.

$$(f\ l/D + k_i + k_e + k_b)_R\ (a_o/a_i)_R^2 = 1$$

where :

k_i : loss coefficient for entry = 1.
k_o : loss coefficient for exit = 1.
k_b : loss coefficient for bends = .9 per bend

$$\frac{(f\ l_R l_c/D_R D_c) + (1+1+0.9*nbend_f)\ A_R^2}{(f\ l_c/D_c) + (1+1+0.9*nbend_c)\ D_R^4} = 1$$

The above equation was solved numerically for different number of bends in the facility's feeders. It was found that reducing the number of bends from 7 to 2 would require a reduction in feeder diameter of about 10%.
The number of bends in the facility will be preserved at 7 per feeder and their actual location will be determined during the final layout. Nevertheless the bends are to be located at the corresponding scaled distances. One of the phenomena of interest may be flooding at the bends immediatly adjacent to the channel. Those locations will not be changed by layout considerations.

Since the two passes of the thermosyphoning facility are designed to be symmetrical the corresponding feeders will have the same geometries.

Table 1 shows the location (1 to 5) for both loops (A and B) of the inlet (I) and outlet (O) feeders.

Feeders have been classified as shown above and the corresponding figure numbers are also given in table 1.

The simplified geometric characteristics of the 10 feeders are given in table 2. In the final design, the actual geometry will be slightly different due to 3-D layout and choice of bend radii. The coordinates given below are between the channel outlet and the respective feeder connection at the header.

In table 2 the foolowing symbols are employed :

D1 : diameter of lower part of feeder
D2 : diameter of upper part of feeder
X : lateral displacement from the side of the channel
Y : vertical distance
Z : axial distance along the channel axes
L1 : length of feeder with a diameter of D1
L2 : length of feeder with a diameter of D2
L : total length of feeder

1.3 Headers

If the headers are scaled using the standard scaling factors their geometries would be determined as follows.

$(a_o / a_H)_R = 1$

$(a_{oc} * 95 / a_{of} * 5) / (a_{Hc} / a_{Hf}) = 1$

$(1/A_R) * (95/5) * (D_f^2/D_c^2) = 1$

This gives the following scaled header geometries.

inlet header ID :	37.5	mm
inlet header length:	3203	mm
outlet header ID :	41.2	mm
outlet header length:	3229	mm

If the analysis is redone considering the headers to be flow resistances (as done earlier in C.1.1 for the end fittings) the geometries would be :

inlet header ID :	167.8	mm
inlet header length:	3203	mm
outlet header ID :	184.1	mm
outlet header length:	3229	mm

In both cases the simply scaled dimensions do not adequately reflect the true functional characteristics of the headers.

In the first case the diameter of the headers are almost equal to the diameter of the feeders. In the second case the volume ratio between the facility and the Candu is 11.8% compared to 0.5% for the core.

In both cases the length cannot be scaled down any more than by the governing length ratio of 0.5.

In order to overcome that difficulty we will consider that a header serves as a flow path from the feeder connection to the steam generator inlet pipes or from the pump discharge pipes to the various feeders. This flow path is the one we scale.

A header can be conceptualised to consist of the four regions below :

i) between one end and the first (discharge or inlet) pipe.
ii) between the first pipe and the center of the header.
iii) between the center of the header and the second pipe.
iv) between the second pipe and the other end.

The average flow path length for the 95 feeders is the average flow path of each region. The average region flow path will be scaled. It should be noted that all regions of the same header type have equal average region flow paths.

In order to scale the header length a decision on the feeder connection to the headers must be made. Thermosyphoning phenomena, as demonstrated in previous experiments may be dictated by channel to channel interaction. Therefore two pairs of channels have been chosen to be connected across from each other for each header in the (a) and (d) regions as defined above. The fith channel is connected in the middle of the header. Feeders are connected with flanges at the header and provision is made to connect a feeder at one of the 3 different radial locations. The unused flanges are closed off. A dead space of half the average scaled flow length is provided at each end of the headers. This implies that the feeders will have five average flow paths.

The average length of each flow path is 1/8 of the total length of the header.

Therefore the header length equals :

$$L_F = L_C * 1/8 * l_R * 5$$

The diameter is determined from the hydraulic diameter of the average flow path which is :

$$D' = D * (4/95)^{1/2}$$

where 95/4 represents the average number of channels per region and D is the ID of the header. The flow area for two channels is :

$$2 * D'^2 * (Pi)/4$$

This leads to a pipe diameter = $2^{1/2} * D'$

The header geometries have been scaled to be :

inlet header ID :	101.9	mm
inlet header length:	2002	mm
outlet header ID :	111.8	mm
outlet header length:	2018	mm

1.4 Process Piping

The process piping includes the following pipes :

i) 2 pipes from outlet header to steam generator
ii) 1 pump suction pipe
iii) 2 pump discharge pipes
iv) 1 pressuriser surge line

The pipes have been scaled according to the following formula :

$$(f\ l/D + k_i + k_e + k_b)_R\ (a_o/a_i)_R^2 = 1$$

where :

k_i : loss coefficient for entry = 1.
k_o : loss coefficient for exit = 1.
k_b : loss coefficient for bends = .9 per bend

$$\frac{(f\ l_R l_c/D_R D_c) + (1+1+0.9*nbend_f)\ A_R^2}{(f\ l_c/D_c) + (1+1+0.9*nbend_c)\ D_R^4} = 1$$

The above equation was solved numerically to obtain the pipe diameter for a given length ratio.

The pressuriser expansion line was scaled as if it was a flow line, scaling by other methods results in smaller diameter. As an example scaling by area ratios gives a diameter of 16.3 mm as compared to 19.1.

Tabulated below are the result of the analyses.

Pipe	ID (mm)	length (mm)	# of bends	volume (dm^3)
OH to SG section 1	42.8	600.0	0	.863
OH to SG section 2	48.4	1650.0	1	3.036
Pump suction	47.1	2250.0	2	3.920
Pump discharge	38.0	1550.0	1	1.758
Pressuriser expansion	19.1	7750.0	5	2.221
OH to OH interconnect	12.5	9350.0	6	3.357

1.5 Steam Generator Primary Side

In order to preserve the phase change characteristics (bubble collapse, flooding, reflux condensation) the steam generator tube diameter is conserved and taken equal to the Candu tube diameter. The steam generator is designed to provide an adequate heat sink for 100% scaled power for 5 channels.

All 3550 steam generator tubes of the Candu 600 are different from each other. The average length of the tube (including the bend but excluding the tube sheet penetration) is 18.76 m. The scaled average length of the steam generator tube for the thermosyphoning facility is computed as :

$$l_f = l_R \, l_c$$

$$l_f = 0.5 * 18\,761 = 9380 \text{ mm}$$

Since both the diameter and the length have been fixed, the only parameter that can be scaled is the number of steam generator tubes.

The steam generator is designed for 100% scale power even though the core heat flux has been scaled for about 10% full scale scaled power. The proper steady state enthalpy distribution is achieved by tuning the temperature of the feedwater. The number of steam generator tubes can be found either by conserving the pressure drops or by conserving heat transfer areas. Those assumptions imply that the steam generator tubes have the same characteristics as those of the Candu steam generator tubes as far as heat transfer is concerned. Another tubing material would require a change in number of tubes or a different adjustment of the secondary side feedwater characteristics or secondary side pressure.

1.5.1 Number of Tubes by Heat Transfer Considerations

The total power generated in the scaled down channels is 0.73% of the power generated by 95 channels of the Candu-600. For the same steam generator tube diameter and half the length, 1.46 % of the original number steam generator tubes are required. The surface area of theses tubes would provide, at identical to Candu secondary side conditions, the heat sink for 100 % power operation. This number of tubes can be found as follows :

$$(N_f \, (Pi) \, D_f \, L_f) \, / \, (N_c \, (Pi) \, D_c \, L_c) = q_R V_R \; 5/95$$

for $D_f = D_c = 13.62$ mm and $L_f = L_c$

$$N_f = N_c \, q_R \, V_R \, / \, L_R \; 5/95$$

$$N_f = 3550 * 1.414 * 0.1958 * 5/95$$

$$N_f = 52 \text{ tubes}$$

A further analysis, however is necessary to ascertain whether a steam generator with this number of tubes would provide the right pressure drop. Since the flow velocities in the facility would only be about 70% of the flow velocity in the Candu, the number of steam generator tubes will be smaller than 52.

1.5.2 Number of Tubes by Pressure Drop Considerations:

According to our scaling methodology, the pressure drop is conserved for :

$$(K + f\ L/D)_R\ (\ a_o/a_i\ )_R^2 = 1$$

Depending upon the tube bend radius that is chosen for the steam generator tubes, the distributed minor loss coefficient K (including its value for entry and exit) can vary from 2 to 4. The friction factor depends upon the flow velocity. Therefore a numerical analysis is necessary to determine the ratio of steam generator tube aggregate flow area and the number of tubes. The above equation can be written as :

$$(K + f_f L_f/D)\ /\ (K + f_c L_c/D) =$$

$$(1/A^2_R)\ (((Pi)\ D^2\ N_f)\ /\ ((Pi)\ D^2\ N_c\ 5/95\ ))^2$$

The above equation was iterated using the following data :

K = 2 to 4
f = f (e/D,Re), Wood's approximation of Colebrook equation.
e/D = 0.000025
Re = 10**5 to 10**8
D = 13.62 mm
N_c = 3550

The results of the analysis, along with a listing of the computer code are given in Appendix. The solution is 28.

In order to preserve the component pressure drop characteristics in the PHTS, the steam generator will be designed with 28 tubes. This would require reduction in secondary side feedwater temperature and pressure to maintain the appropriate heat sink. Since we can always adjust the secondary side characteristics of the steam generator, it is preferable to size the steam generator for its hydraulic resistance.

The steam generator will reflect the design of the Foster Wheeler steam generators in that an internal annulus shroud for recirculation and integral cyclone steam separators will be included. The actual height of the steam generator will depend upon the design of the steam generator equipment and will be specified by the vendor. A first order guess can be made using the overall length of the tubes. The actual design of the downcomer (whether internal or external) can be specified by the vendor upon economy. In any case the preheater has to be included in the design since it could have a major effect on the thermosyphoning driving force above the headers. In addition the Candu 600 preheater design is also claimed to have a major effect during scenario with Emergency Water Supply actuation.

Steam generator primary side data :

Number of tubes	28	
Overall height	6500	mm
Average tube length	9380	mm
Average tube height	4500	mm
Tube ID	13.62	mm
Tube OD	15.88	mm
Inlet/Outlet Plenum Diameter (approx.)	520	mm

1.6 Pump

A non passive equipment such as a primary pump cannot be scaled down with the scaling laws we have been using sofar. Nevertheless the pump specification can be given, since the flows and pressure distribution are known. The characteristics of the pump are as follows :

Maximum flow	4	kg/s
Pump suction pressure	9.5	MPa
Pump discharge pressure	11.24	Mpa
Inlet temperature	266	°C

A pump resistance feedback may be necessary depending on pump manufacturer. The resistance of a Candu 600 pump is estimated to have a k value equal to 17.7 when the pump is stopped. In case of a lower resistance of the facility's pump an orifice can be adapted to the pump lines.

Depending on the pump characteristics (head versus speed) the variable speed pump can be programmed and controlled with feedeback such as to duplicate the pump rundown of a Candu 600. In any case the rundown characteristic of the pump will be factored into the test matrix of the experiments and will form an integral part of the facility characterisation programme.

2. Pressuriser

The pressuriser similar to pumps, cannot be scaled down with the scaling laws we have employed. The pressuriser will therefore be scaled down according to its function as an expansion tank. In the Candu 600 the design basis of its size is the requirement to accomodate the thermal schrinkage from full to decay power.

The PHTS fluid volume for the facility is determined as follows:

Inlet headers	33	dm^3
Outlet headers	40	dm^3
Steam generators (tubes + plena)	165	dm^3
Pumps (estimate)	9	dm^3
Feeders	77	dm^3
Channels	40	dm^3
Large pipes	30	dm^3
Total volume	394	dm^3

$VP_c / VP_f = V_c / V_f$

$VP_f = 394 / 120. * 45.31 = 150\ dm^3$

At this point we can set the pressuriser height to be 3m and allow 2m free space for steam pressure control. At 100% power the volume ratio between steam and water in the pressuriser is about 2 to 1. We can then calculate the pressuriser diameter.

volume = (Pi) * D * D * height / 4

$D = (4 * volume / ((Pi) * height))^{1/2} = 252\ mm$

Similar volume scaling can be employed to establish the size of the pressuriser heaters. The Candu 600 pressuriser consists of 5 immersion heaters at 200 kW each. For a system volume ratio of (.394/120) one bank of two heaters, 2 kW each, with one of them on variable control is specified. The pressuriser spray system draws from the inlet header and its controlled flow injection is designed to equilibrate the heaters when both heaters and spray are operating.

3. Steam Generator Secondary Side

The design basis of the secondary side feedwater is based on the assumption that each steam generator should be able to remove 0.5 MW with feedwater that is subcooled at about 180°C and with a steam outlet of 99.5% quality at a pressure of 4.73 MPa.

The feedwater flow and enthalpy will be used to establish the appropriate heat sink and to tune the primary system conditions and obtain the required enthalpy distribution in the PHTS.

To define the feedwater flow required for the facility we will use the heat loads to the steam generators of the Candu and the facility.

Heat load to one steam generator in the Candu :

2064 / 4 = 516 MW

Heat load to one steam generator in the facility at 100% scaled power :

516 * 5/95 * .1385 = 3.76 MW

The facility's core will be run at about 10% scaled power depending on heater design and final specifications. The feedwater flow will be designed to accomodate 15% of scaled power.

Maximum heat load to maximum scaled core power :

3.76 * .15 = .564 MW

Maximum required feedwater flow :

.564 / 516 * 259 = .283 dm^3/s

Feed water inlet temperature 187 °C

4. Emergency Water Supply

The emergency water supply is scaled such as to provide an equivalent cooling flow to the rig's steam generator as provided in the Candu. The scaling will be done on relative core powers.

The EWS is actuated when the power is about equal to 2.5% of full power which translates to a load of 12.9 MW (2064*2.5%/4) per steam generator.

In the facility the load to one steam generator will be :

2064 * 2.5% / 4 * .1385 * 5/95 = 94 kW

The cooling flow will then be :

94 kW / 12.9 MW * 30 dm^3/s = .22 dm^3/s

The emergency water supply temperature is set equal to 20 °C as in the Candu. With that temperature the calculated flow is almost sufficient to remove the heat generated by the core without steam generation and therefore to refill he empty steam generators in the long term cooling.

Emergency Feedwater characteristics :

Flow (per steam generator)	.22	dm^3/s
Inlet temperature	20	°C

5. Shutdown Cooling System

The shutdown cooling system has two modes of operation in the Candu 600. The first mode uses the PHTS primary pump to generate the core flow, the second mode uses the shutdown cooling pumps and heat exchangers. In the design of the facility we will consider only the second mode of operation.

The SDCS is scaled using power to volume scaling. The flow through one loop in the Candu is equal to 91 l/s.

SDCS flow for the facility :

91 * 5/95 * .1385 = .66 l/s

Equilibrium (long term) conditions :

SDCS core inlet temperature	38	°C
SDCS core outlet temperature	54	°C

Normal maximum operating conditions :		
SDCS inlet temperature	90	°C
SDCS outlet temperature	177	°C
Emergency conditions :		
SDCS inlet temperature	200	°C
SDCS outlet temperature	261	°C
Heat exchanger shell side data :		
Inlet temperature	20	°C
Maximum outlet temperature	95	°C
Maximum service water flow	1.36	l/s
Maximum pressure	1.	MPa
Maximum tube side pressure	12.9	MPa

6. Emergency Core Cooling System

The emergency core cooling system (ECCS) of the facility is specially designed for small breaks loss of coolant accident simulation. The size of the Candu 600 ECCS accumulators is chosen such as to be equal to four times the total volume of the PHTS. This enables break flows to last about 1000s before the medium stage ECCS has to be actuated.

A similar design rationale is chosen for the facility ECCS.

ECCS accumulator volume :

4 * 400 l = 1600 l

The initial pressure of the ECCS will be 4.0 MPa. If we suppose that the core is 70% voided before ECC injection begins the average break flow out of the PHTS will be :

$(1600 - .70 * 400) / 1000 = 1.32\ dm^3/s$

At 1.2 MPa the accumulator will be shutoff and the medium stage ECC system will be actuated. The maximum flow it should deliver at that time will be 1 dm^3/s for a system pressure of 1.2 MPa.

The long term ECC system can use the same pump as the medium term system by throttling a valve or switching the main injection line through an orificed bypass line to reduce the pressure at the header location.

ECC characteristics :

Accumulator volume	1600	dm^3
Accumulator maximum pressure	4.0	MPa
Accumulator water temperature	20	°C
Pump shutoff head	1.3	MPa
Maximum pump flow	10	l/s
Pump flow at 1.2 MPa	1	l/s
Pump inlet temperature first stage	20	°C
Pump inlet temperature second satge	90	°C

7. Feed & Bleed

Volume scaling is employed to determine the size of the feed and bleed system. The design value of 16.7 litres/s feed rate in a Candu 600 is prorated down as :

Feed flow characteristics :

.4 / 120 * 16.7 = .06 l/s

During normal operation the feed and bleed flows equal each other. The bleed flow will be regulated with a metering valve and flow measurement. The system would be designed to handle a maximum bleed flow rate of 0.1 dm^3/s.

Feed and bleed characteristics :

Maximum feed flow	.07	dm^3/s
Feed temperature	66	$°C_3$
Maximum bleed flow	0.1	dm^3

8. Noncondensible Injection and Removal

The noncondensible injection system has to simulate the formation of hydrogen during degraded core cooling followed by a zirconium water reaction. Its purpose is to seal the top of the steam generator tubes with a gas bubble and potentially prevent thermosyphoning flows through the steam generators. A high pressure helium bottle (20 MPa), equipped with a pressure regulator flow control valve, connected to one inlet line per steam generator will be used to perform that task.

The removal of the gas will be done using the primary pump and flashing the system to force the gas into the pressuriser where it can be vented. A special pressuriser connection will have to be implemented for that purpose.

9. Facility safety systems

The thermosyphoning facility is a high pressure, high temperature facility whose design incorporates the following safety guidelines and features :

i) Mechanical barrier between personnel and the high pressure loop. This is specified in the system layout.
ii) Physical isolation and visual monitoring of the loop and associated systems from the control room.
iii) Isolation of electrical power lines, instrumentation and control wiring.
iv) Duplicate pressure relief valves.

Following system abnormalities, whether they result as a consequence of experimental conditions or component failure are monitored for :

i) Overpressure
ii) High heater rod temperature in core
iii) High heater rod temperature in the pressuriser.
iv) Low pressuriser level.
v) Loss of feedwater during normal operation.
vi) Loss of service water.
vii) Loss of primary coolant.

System overpressure relief valves are specified both for the PHTS and the secondary sides.

The top pin of each channel is instrumented with wall sheath thermocouple.

The pressuriser heaters are monitored for overheating following low pressuriser level.

Table 1

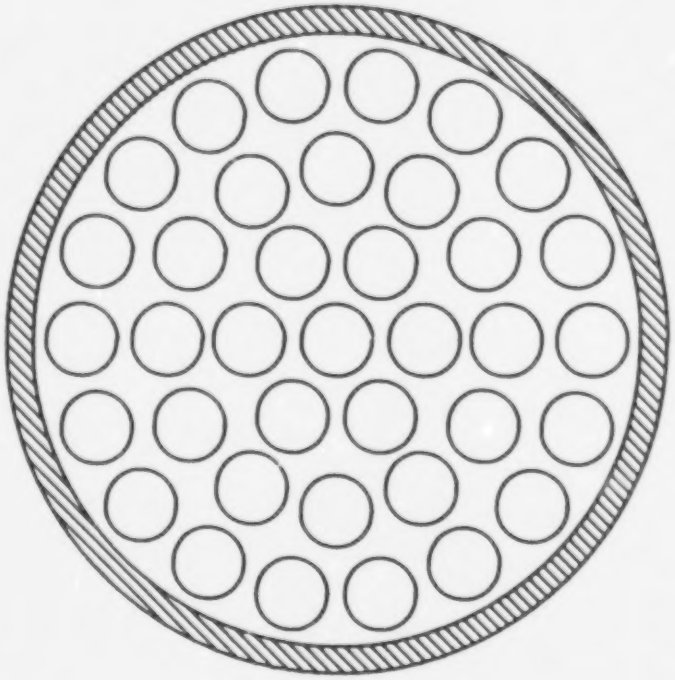
Feeder number and locations

Pass	Channel	Feeder type	Feeder number	Figure number
A	1	inlet	A1-I	18
A	2	inlet	A2-I	19
A	3	inlet	A3-I	20
A	4	inlet	A4-I	21
A	5	inlet	A5-I	22
A	1	outlet	A1-0	23
A	2	outlet	A2-0	24
A	3	outlet	A3-0	25
A	4	outlet	A4-0	26
A	5	outlet	A5-0	27
B	1	inlet	B1-I	28
B	2	inlet	B2-I	29
B	3	inlet	B3-I	30
B	4	inlet	B4-I	31
B	5	inlet	B5-I	32
B	1	outlet	B1-0	33
B	2	outlet	B2-0	34
B	3	outlet	B3-0	35
B	4	outlet	B4-0	36
B	5	outlet	B5-0	37

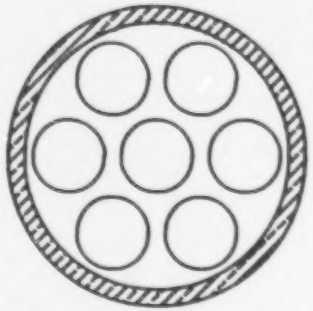
Table 2

Feeders reduced characteristics

Feeder number	D1 mm	D2 mm	X mm	Y mm	Z mm	L1 mm	L2 mm	L mm	Volume dm^3
A1-I	22.7	--	460	2129	1519	4041	--	4041	1.635
A2-I	17.1	--	1175	3129	1519	6333	--	6333	1.454
A3-I	22.7	27.5	389	3128	1519	2088	3020	5108	2.639
A4-I	17.1	--	1175	3129	1519	6333	--	6333	1.454
A5-I	22.8	28.4	2889	4415	1519	4792	3908	8700	4.432
A1-0	28.4	--	460	2129	2383	4894	--	4894	3.100
A2-0	22.6	28.5	1246	3129	2383	1131	5403	6534	3.900
A3-0	28.4	39.7	389	3129	2383	2717	3396	6113	5.925
A4-0	22.6	28.5	1246	3129	2383	1131	5403	6534	3.900
A5-0	28.4	39.8	2889	4415	2383	2877	6569	9447	9.995
B1-I	22.7	--	460	2129	1519	4041	--	4041	1.635
B2-I	17.1	--	1175	3129	1519	6333	--	6333	1.454
B3-I	22.7	27.5	389	3128	1519	2088	3020	5108	2.639
B4-I	17.1	--	1175	3129	1519	6333	--	6333	1.454
B5-I	22.8	28.4	2889	4415	1519	4792	3908	8700	4.432
B1-0	28.4	--	460	2129	2383	4894	--	4894	3.100
B2-0	22.6	28.5	1246	3129	2383	1131	5403	6534	3.900
B3-0	28.4	39.7	389	3129	2383	2717	3396	6113	5.925
B4-0	22.6	28.5	1246	3129	2383	1131	5403	6534	3.900
B5-0	28.4	39.8	2889	4415	2383	2877	6569	9447	9.995

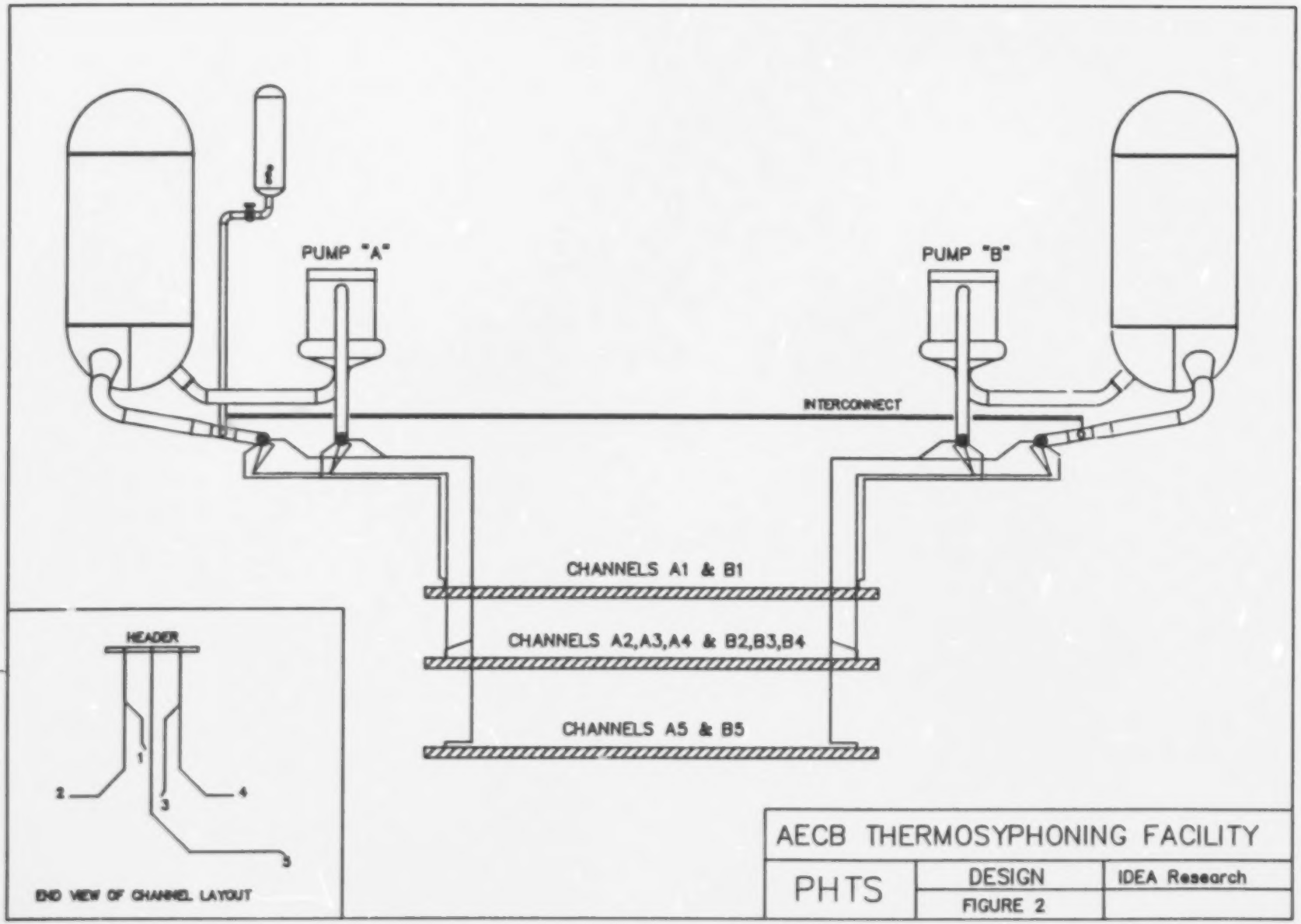


THE CANDU-600 FUEL BUNDLE
37 PINS 13.12 mm O.D.



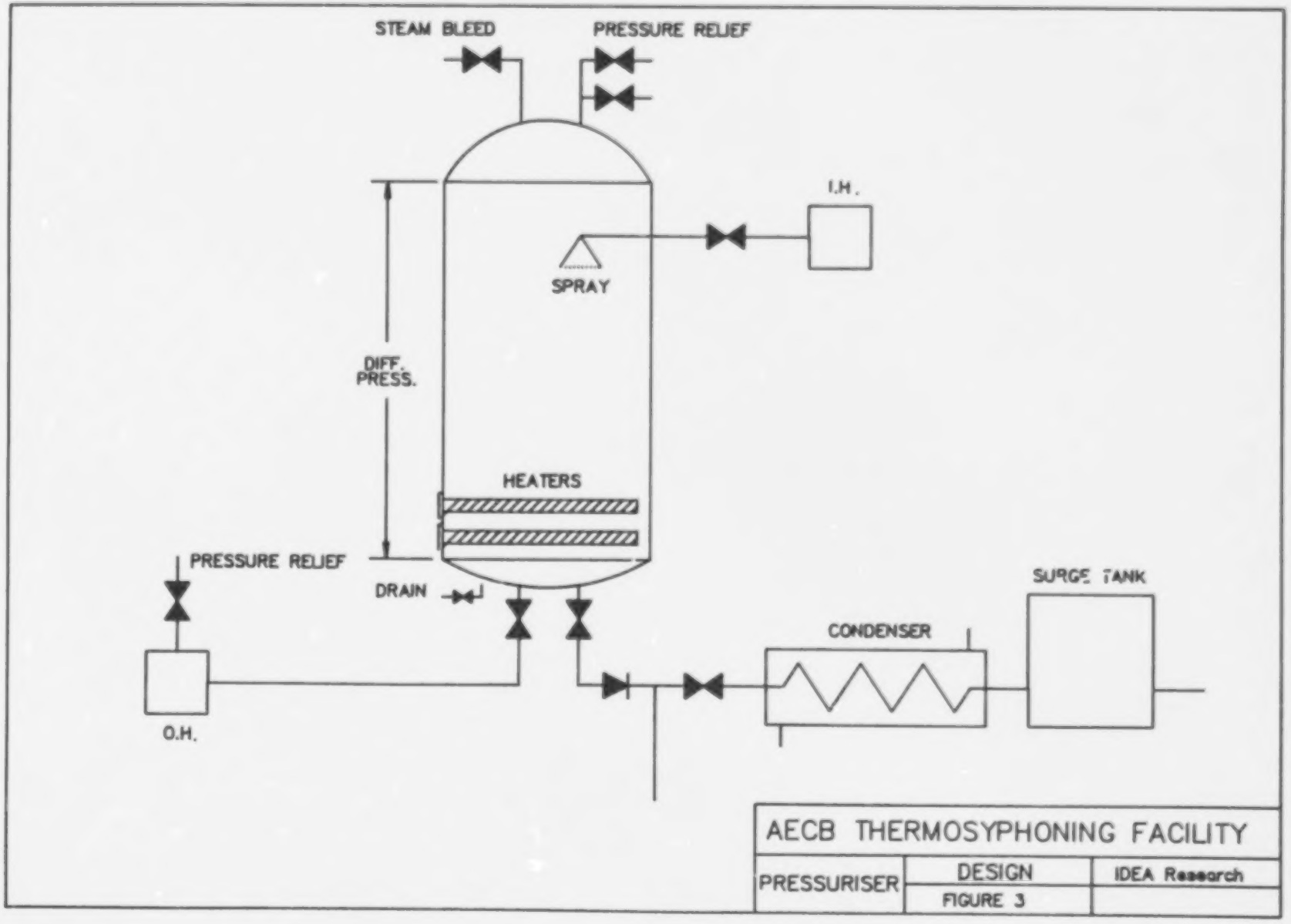
FACILITY FUEL BUNDLE
7 PINS (13.12 mm O.D.)

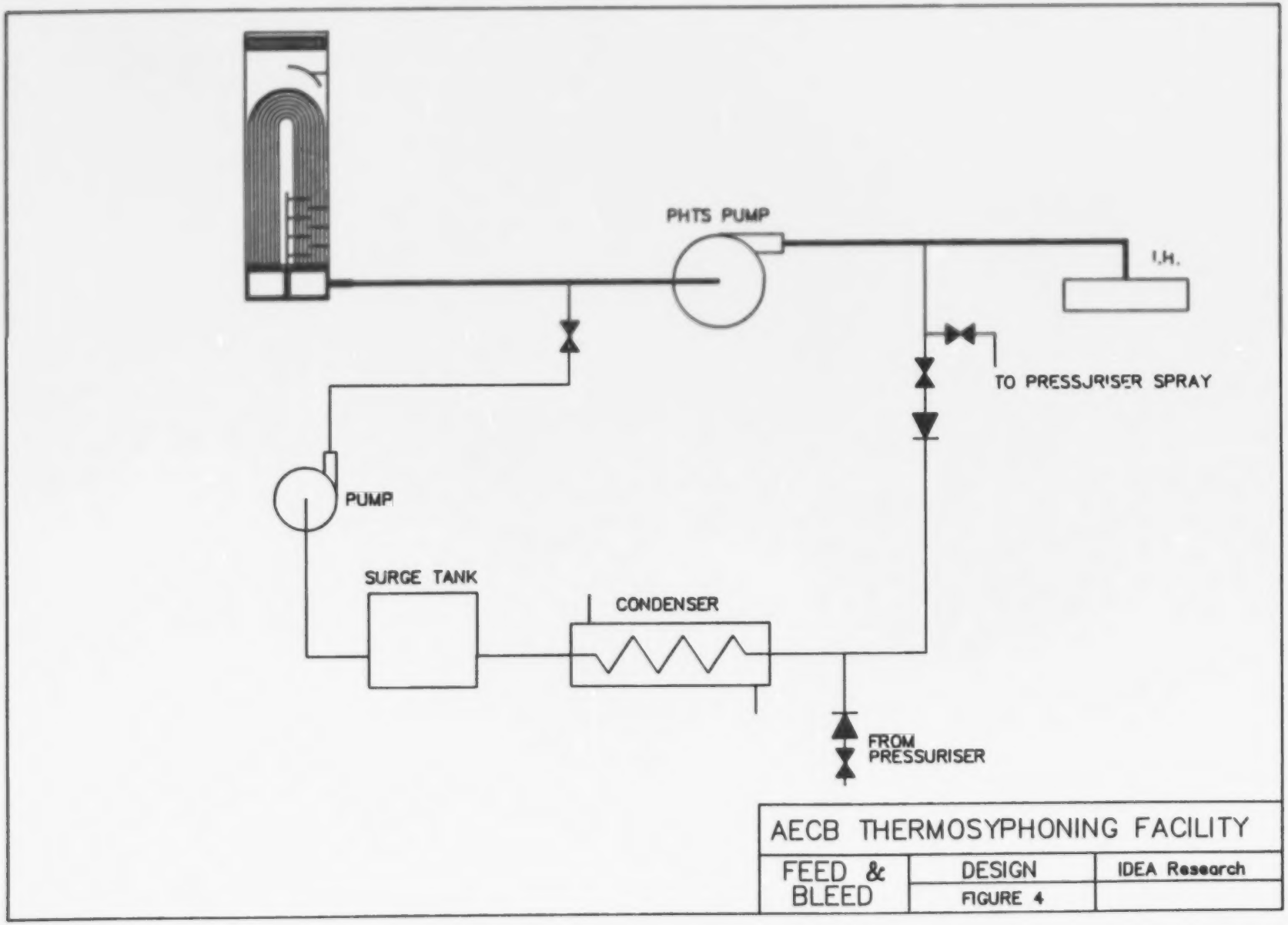
AECB THERMOSYPHONING FACILITY		
FUEL BUNDLES	DESIGN	IDEA Research
	FIGURE 1	

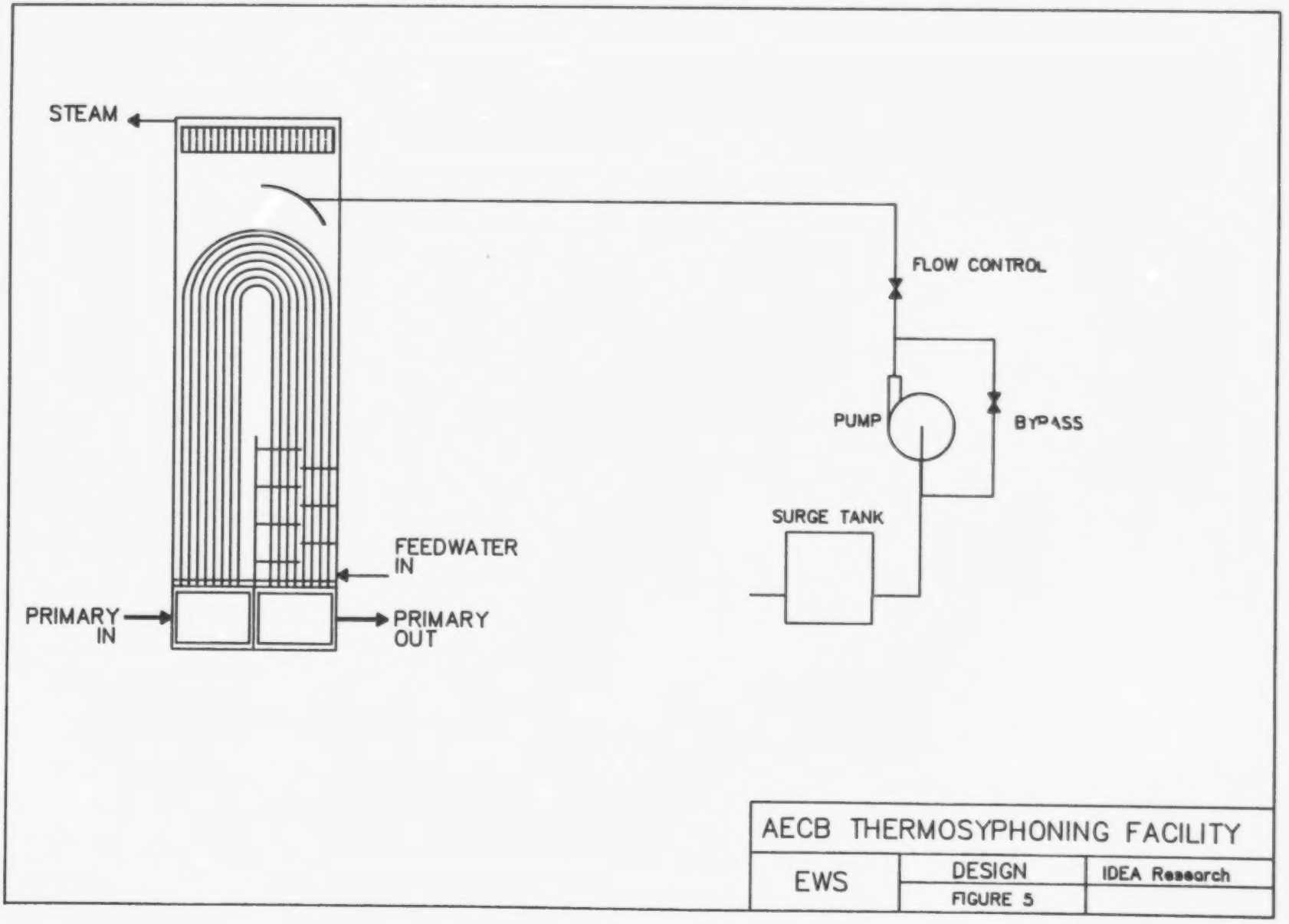


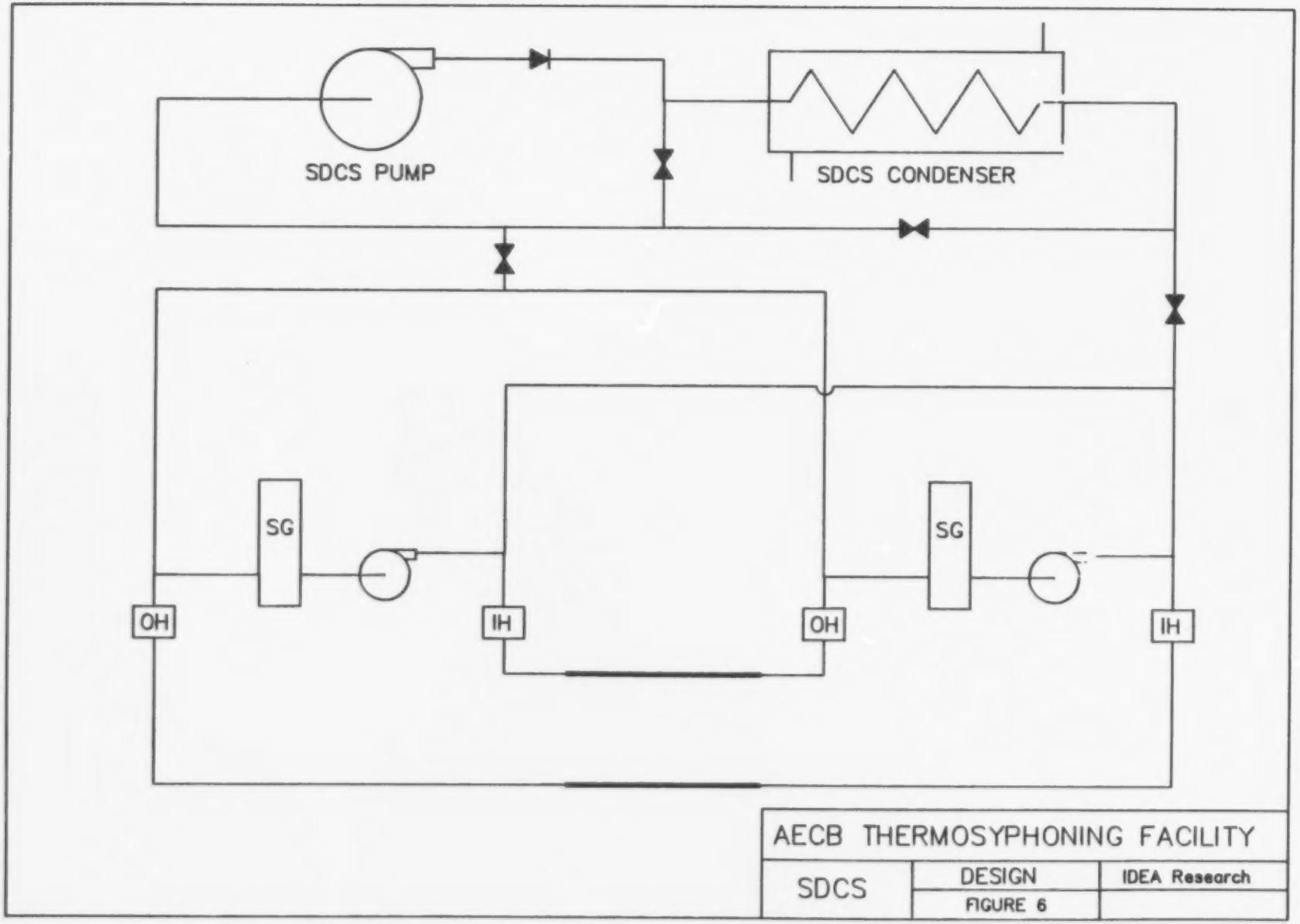
AECB THERMOSYPHONING FACILITY

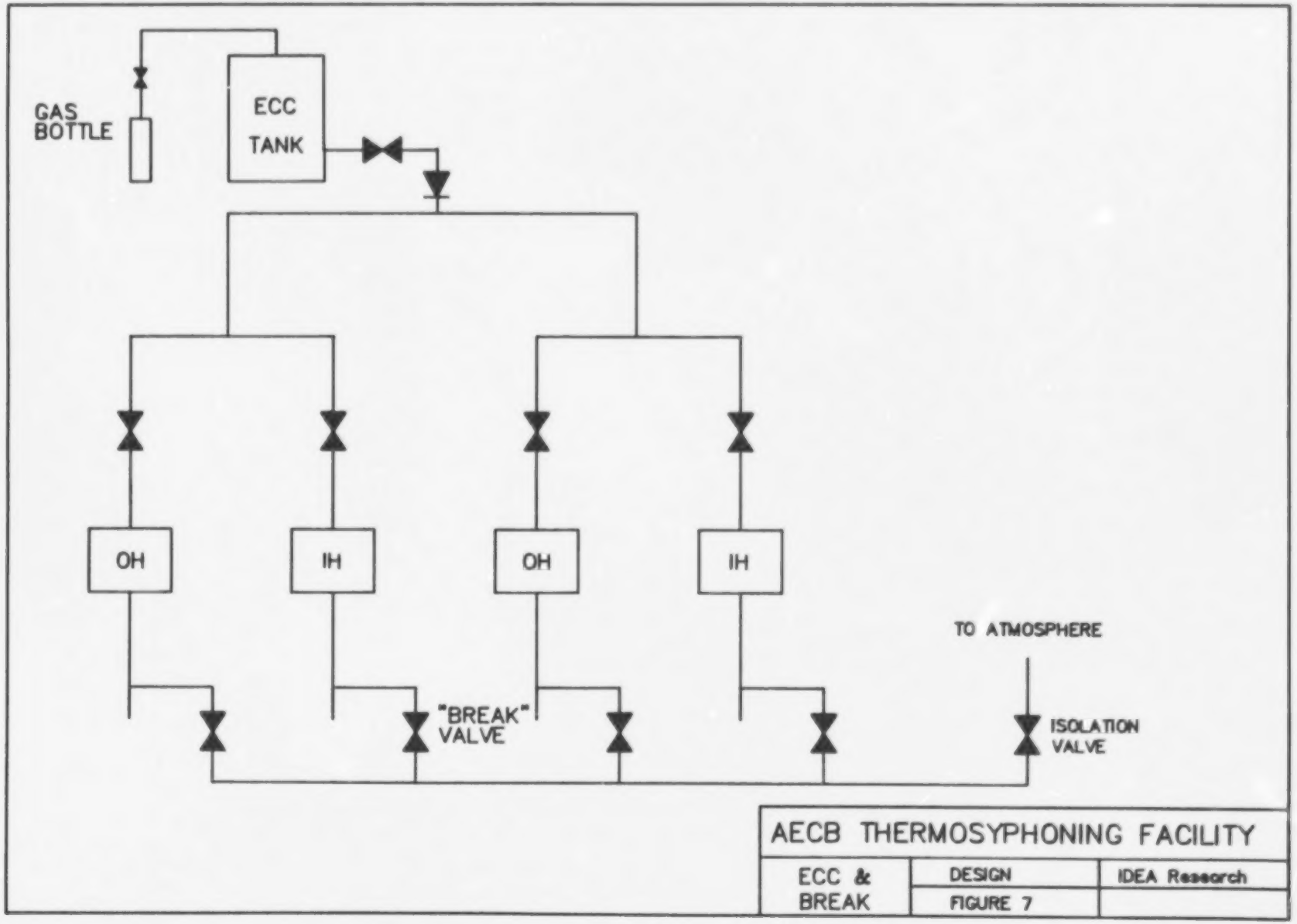
PHTS	DESIGN	IDEA Research
	FIGURE 2	

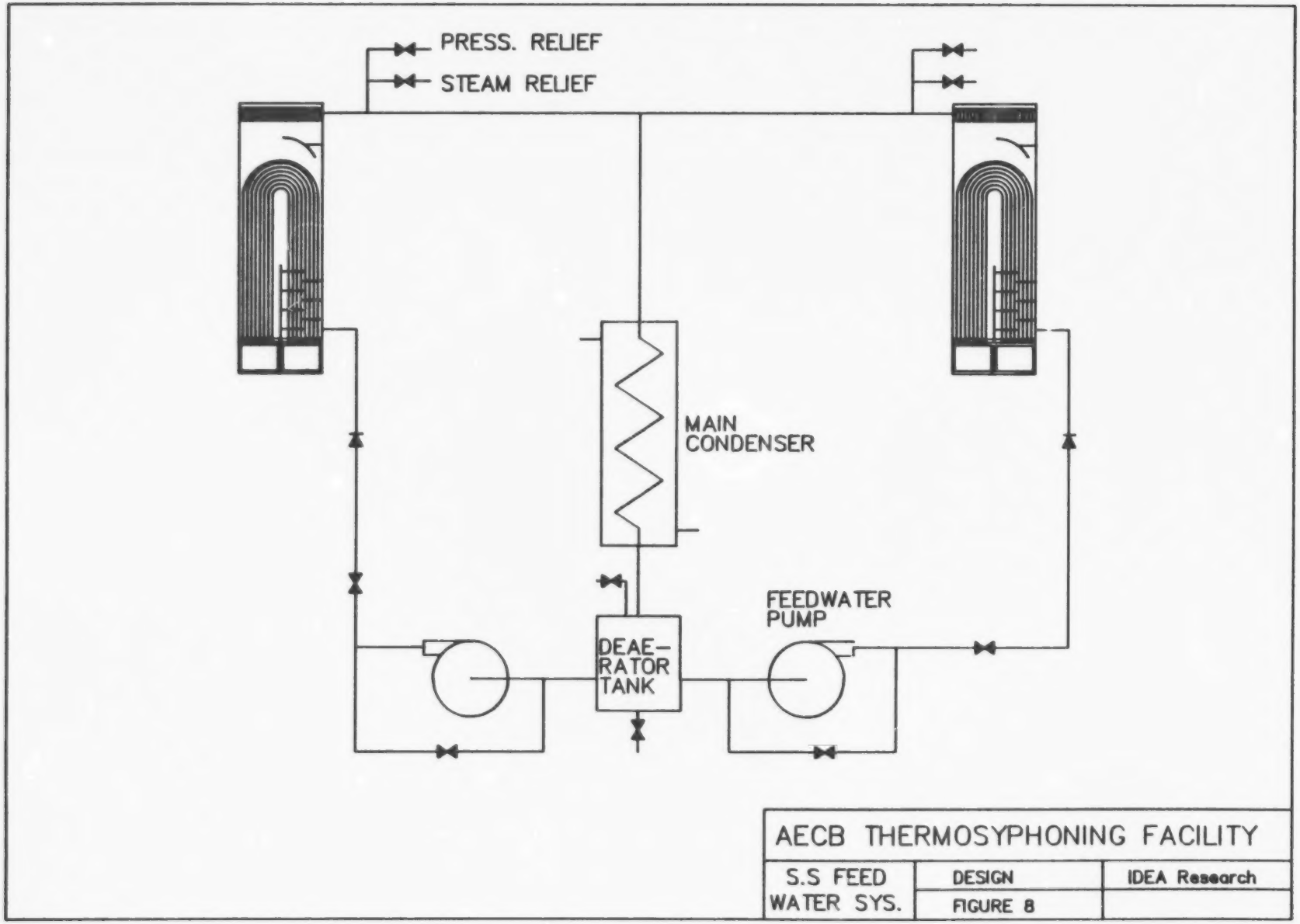

STEAM BLEED
PRESSURE RELIEF
I.H.
SPRAY
DIFF. PRESS.
HEATERS
PRESSURE RELIEF
DRAIN
SURGE TANK
CONDENSER
O.H.
AECB THERMOSYPHONING FACILITY
PRESSURISER
DESIGN
IDEA Research
FIGURE 3

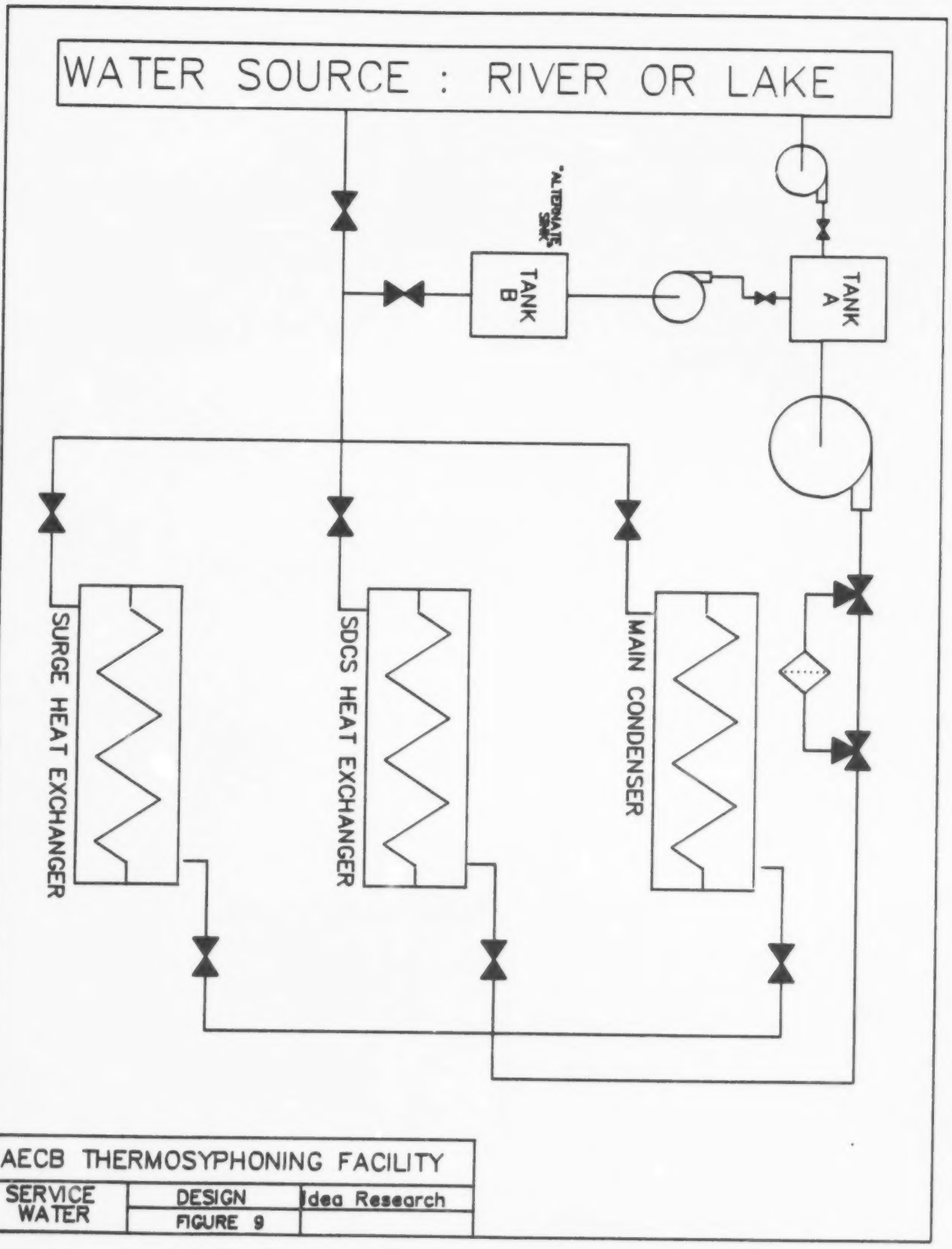

PHTS PUMP
I.H.
TO PRESSURISER SPRAY
PUMP
SURGE TANK
CONDENSER
FROM PRESSURISER
AECB THERMOSYPHONING FACILITY
FEED & BLEED
DESIGN
FIGURE 4
IDEA Research


STEAM
FLOW CONTROL
PUMP
BYPASS
SURGE TANK
FEEDWATER IN
PRIMARY IN
PRIMARY OUT
AECB THERMOSYPHONING FACILITY
EWS
DESIGN
IDEA Research
FIGURE 5


SDCS PUMP
SDCS CONDENSER
SG
SG
OH
IH
OH
IH
AECB THERMOSYPHONING FACILITY
SDCS
DESIGN
IDEA Research
FIGURE 6

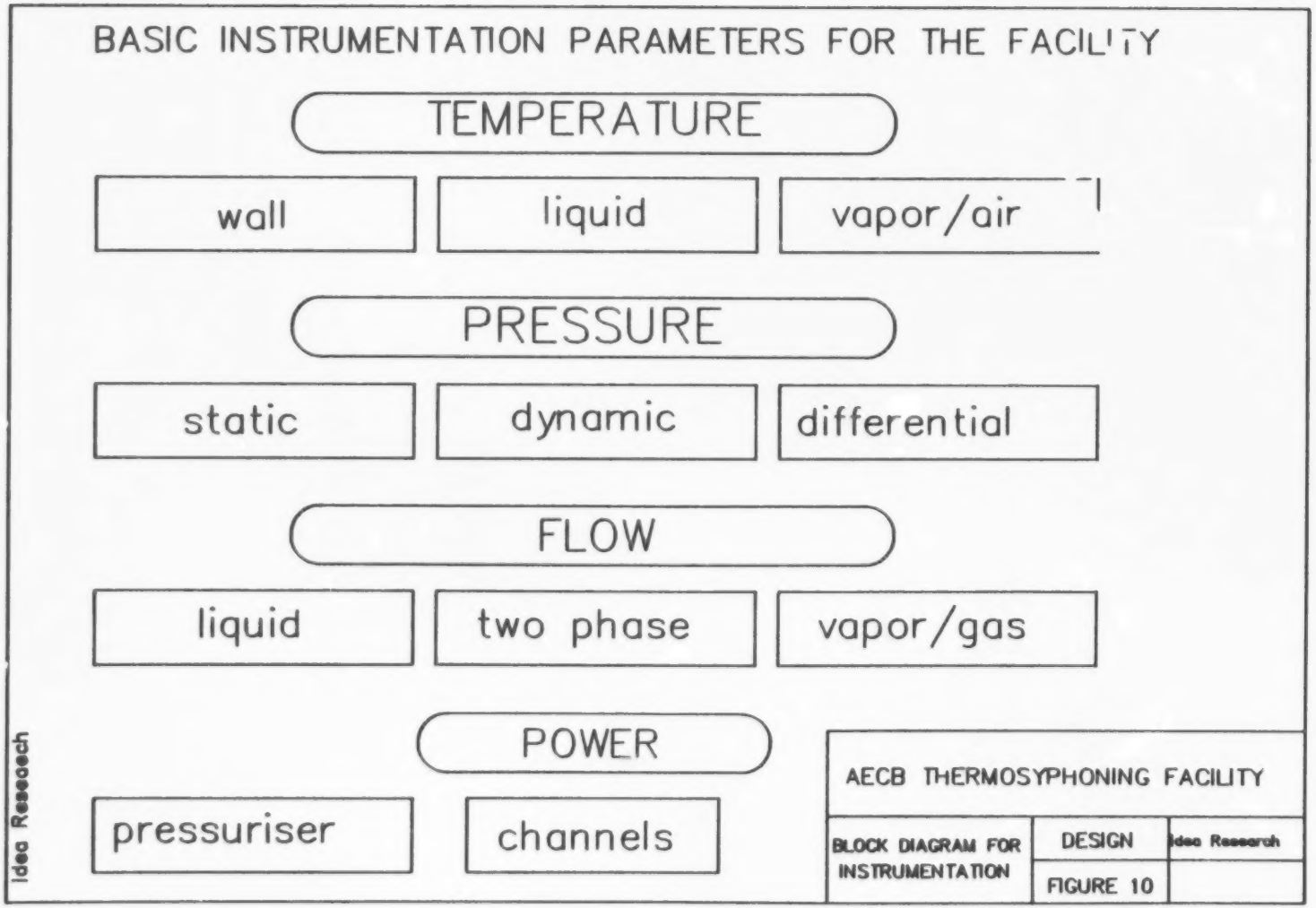

GAS
BOTTLE
ECC
TANK
OH
IH
OH
IH
"BREAK"
VALVE
TO ATMOSPHERE
ISOLATION
VALVE
AECB THERMOSYPHONING FACILITY
ECC &
BREAK
DESIGN
FIGURE 7
IDEA Research


PRESS. RELIEF
STEAM RELIEF
MAIN CONDENSER
FEEDWATER PUMP
DEAE-RATOR TANK
AECB THERMOSYPHONING FACILITY
S.S FEED WATER SYS.
DESIGN
FIGURE 8
IDEA Research

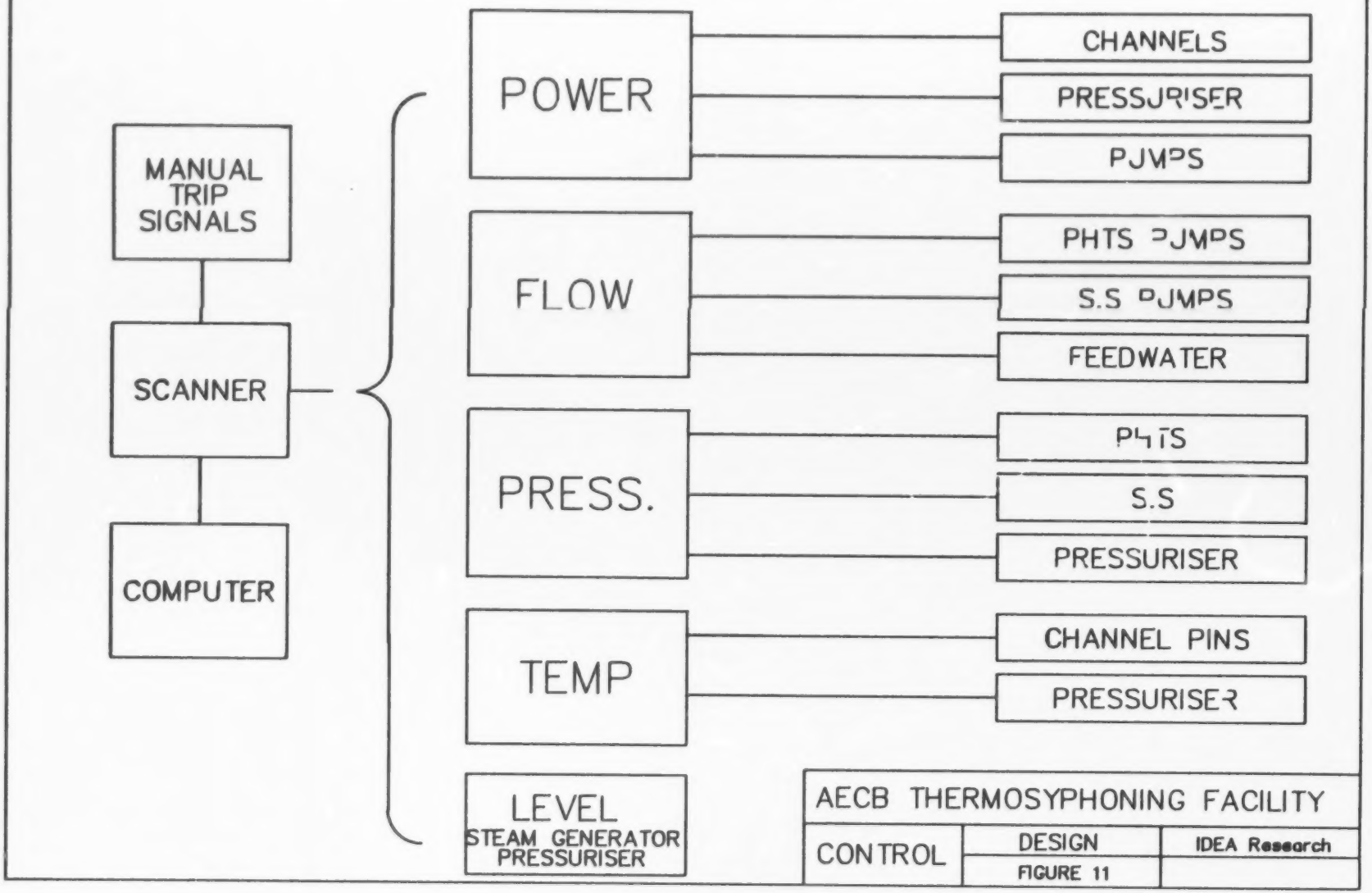


AECB THERMOSYPHONING FACILITY

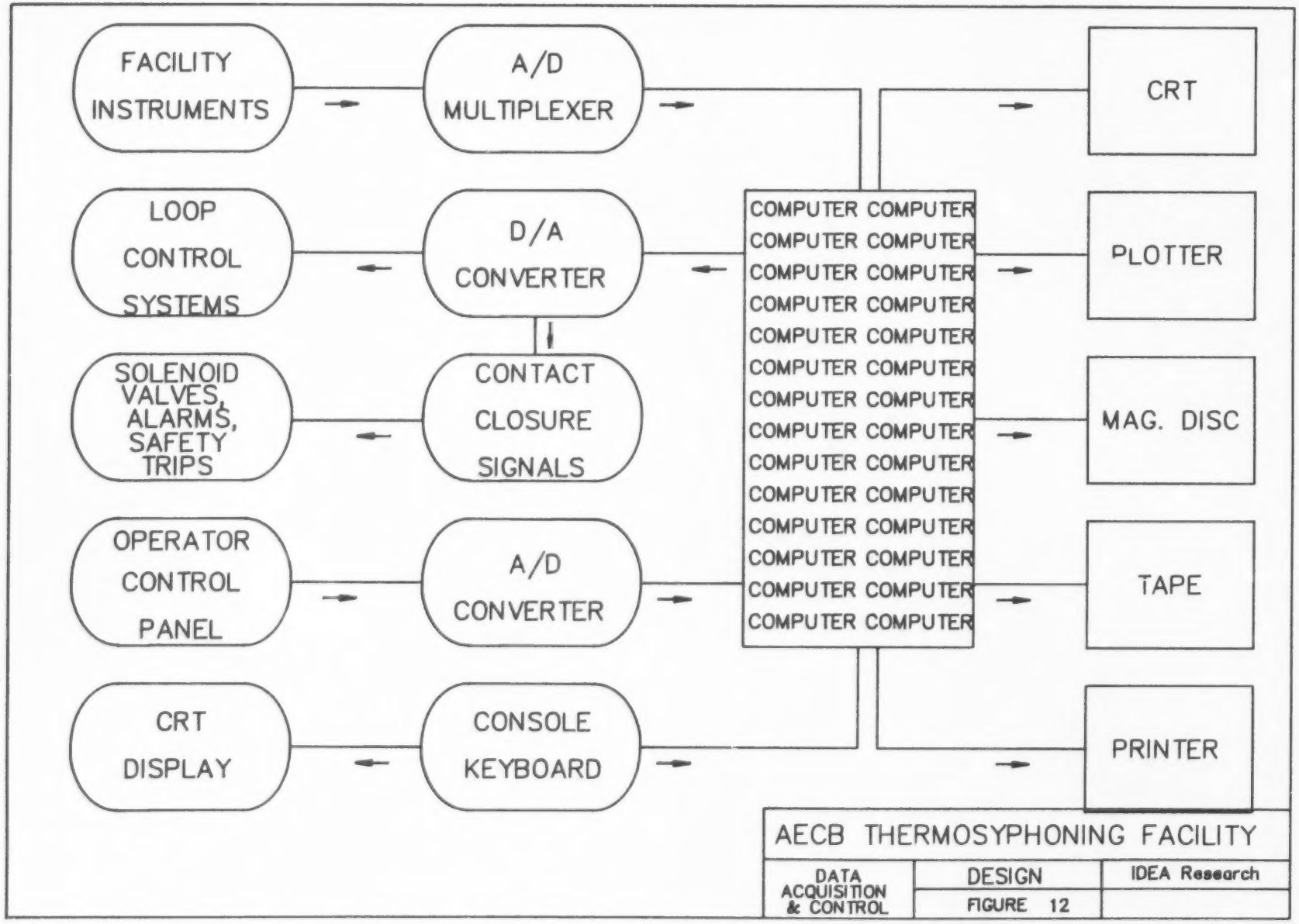
SERVICE WATER	DESIGN	Idea Research
	FIGURE 9	


BASIC INSTRUMENTATION PARAMETERS FOR THE FACILITY
TEMPERATURE
wall
liquid
vapor/air
PRESSURE
static
dynamic
differential
FLOW
liquid
two phase
vapor/gas
POWER
pressuriser
channels
Idea Research
AECB THERMOSYPHONING FACILITY
BLOCK DIAGRAM FOR INSTRUMENTATION
DESIGN
Idea Research
FIGURE 10

FEEDBACK–CONTROL BLOCKS



AECB THERMOSYPHONING FACILITY		
CONTROL	DESIGN	IDEA Research
	FIGURE 11	


FACILITY INSTRUMENTS
A/D MULTIPLEXER
CRT
LOOP CONTROL SYSTEMS
D/A CONVERTER
PLOTTER
SOLENOID VALVES, ALARMS, SAFETY TRIPS
CONTACT CLOSURE SIGNALS
MAG. DISC
OPERATOR CONTROL PANEL
A/D CONVERTER
TAPE
CRT DISPLAY
CONSOLE KEYBOARD
PRINTER
COMPUTER COMPUTER
AECB THERMOSYPHONING FACILITY
DATA ACQUISITION & CONTROL
DESIGN
FIGURE 12
IDEA Research

SYSTEM TRIPS FOR SAFETY

CONDITION	SAFETY TRIP
OVERPRESSURE	PRESSURE RELIEF PRESSURISER POWER TRIP CORE POWER TRIP
HIGH CORE TEMP.	CORE POWER TRIP PHTS PUMP RESTART
LOCA	SYSTEM POWER TRIP
LOW PRESSURISER LEVEL	PRESSURISER POWER TRIP
LOSS OF FEEDWATER	HEATER POWER TRIP PHTS PUMP RESTART SYSTEM POWER TRIP

FACILITY SAFETY BARRIERS

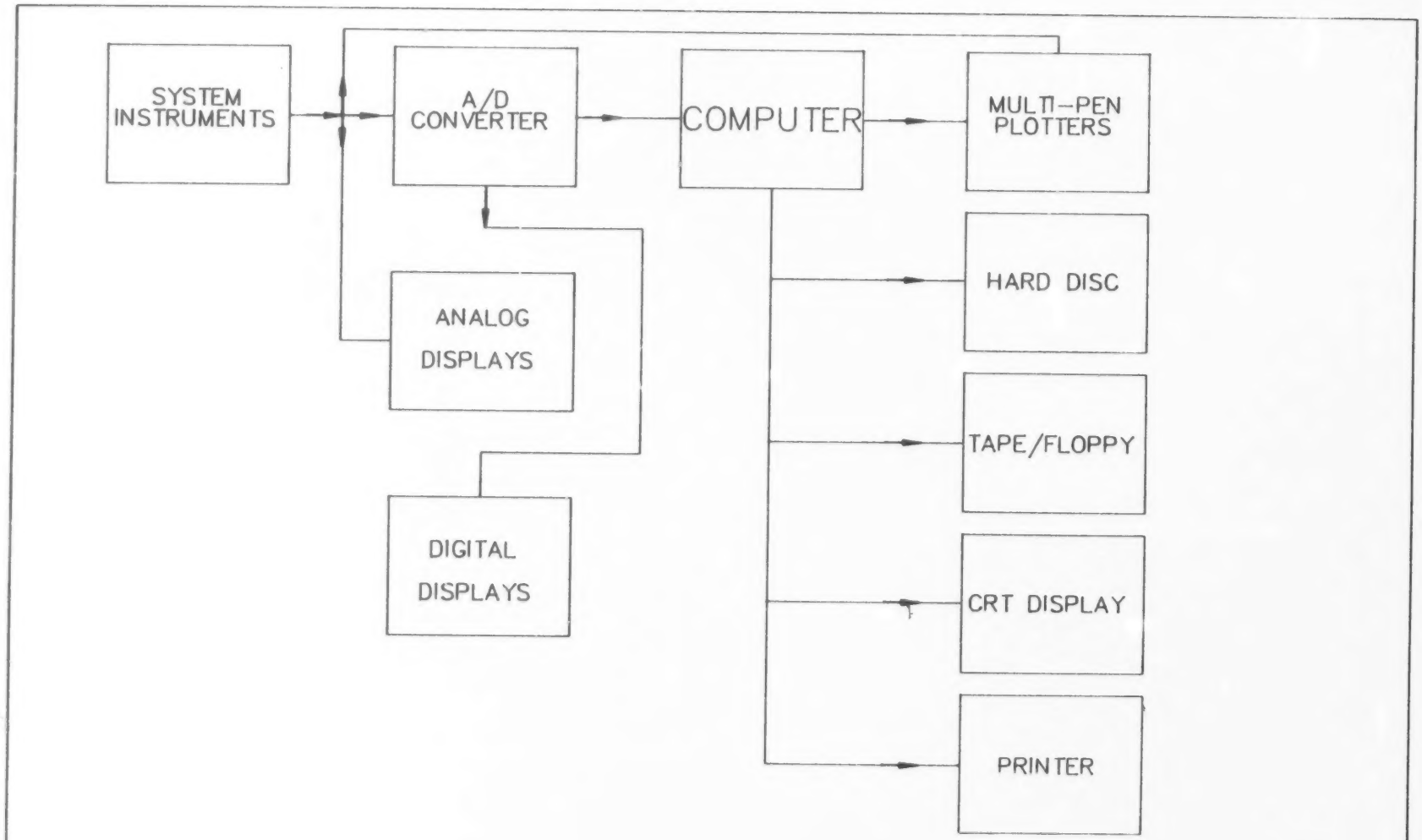
MECHANICAL BARRIER BETWEEN HIGH PRESSURE LOOP & PERSONNEL

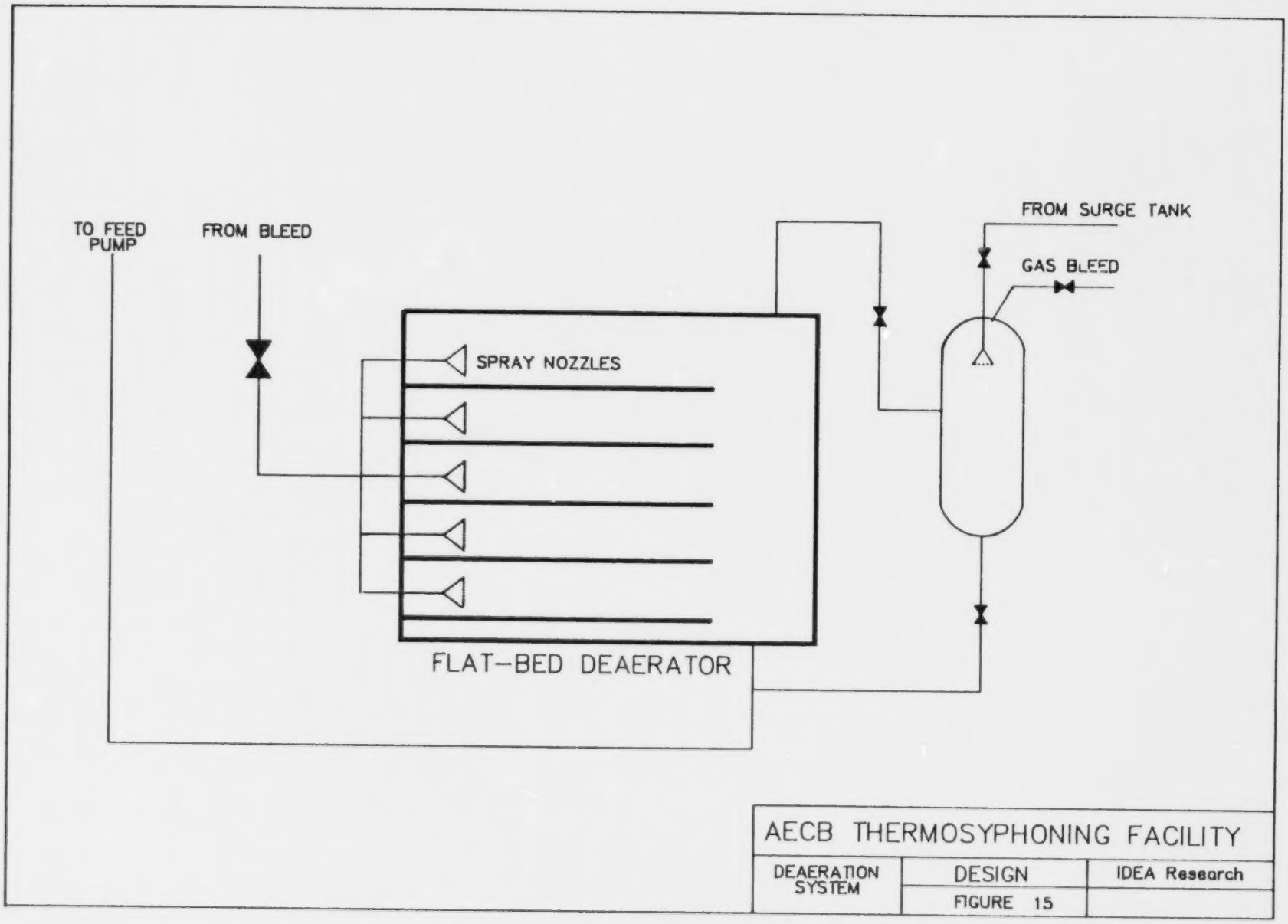
ISOLATED CONTROL ROOM

ISOLATION OF ELECTRICAL SYSTEM

SEPERATION OF INSTRUMENTATION, CONTROL & POWER LINES

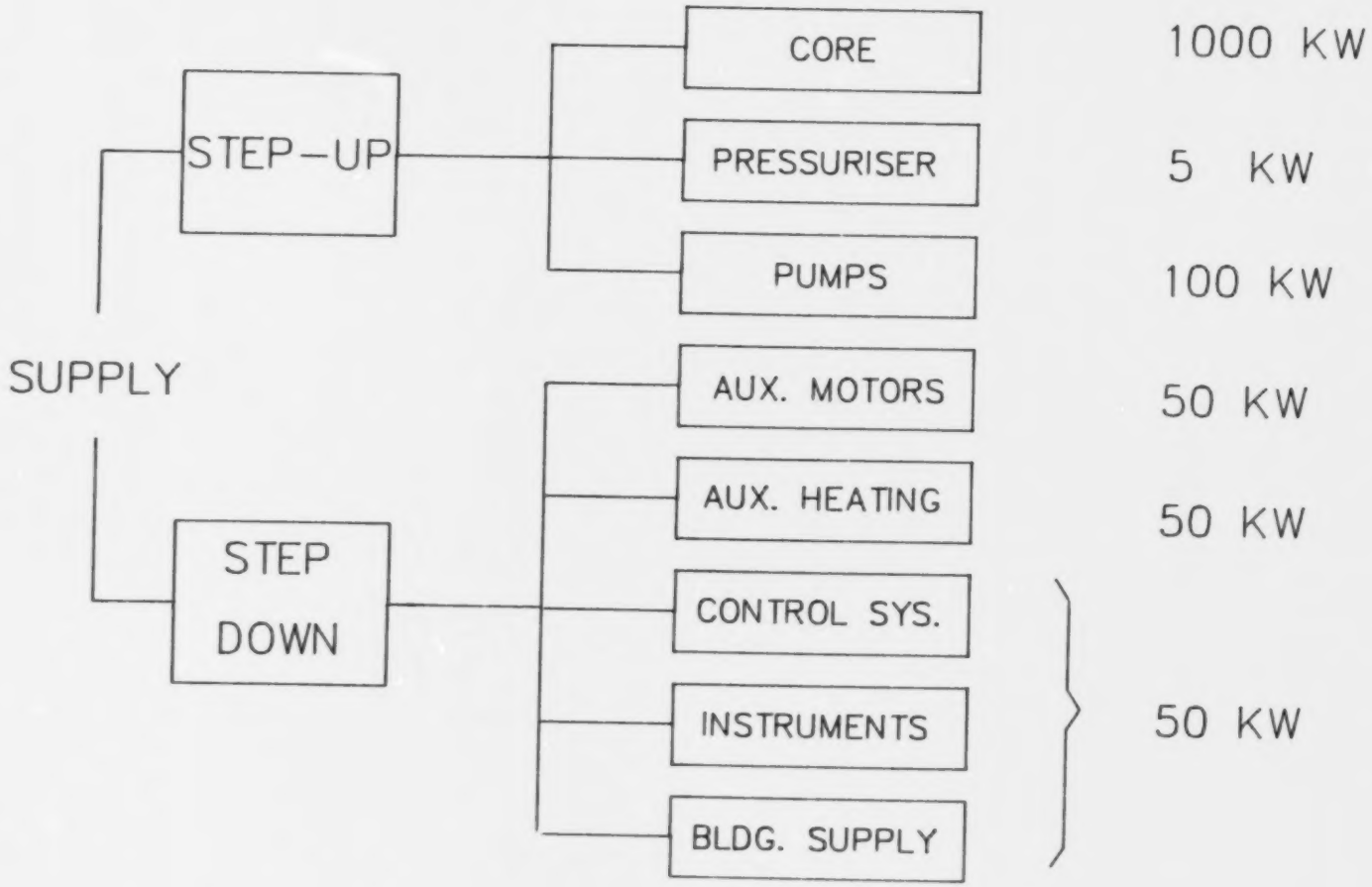
AECB THERMOSYPHONING FACILITY		
SAFETY	DESIGN FIGURE 13	IDEA Research


SYSTEM INSTRUMENTS
A/D CONVERTER
COMPUTER
MULTI-PEN PLOTTERS
HARD DISC
ANALOG DISPLAYS
TAPE/FLOPPY
DIGITAL DISPLAYS
CRT DISPLAY
PRINTER
AECB THERMOSYPHONING FACILITY
DATA STORAGE & DISPLAY
DESIGN
FIGURE 14
IDEA Research



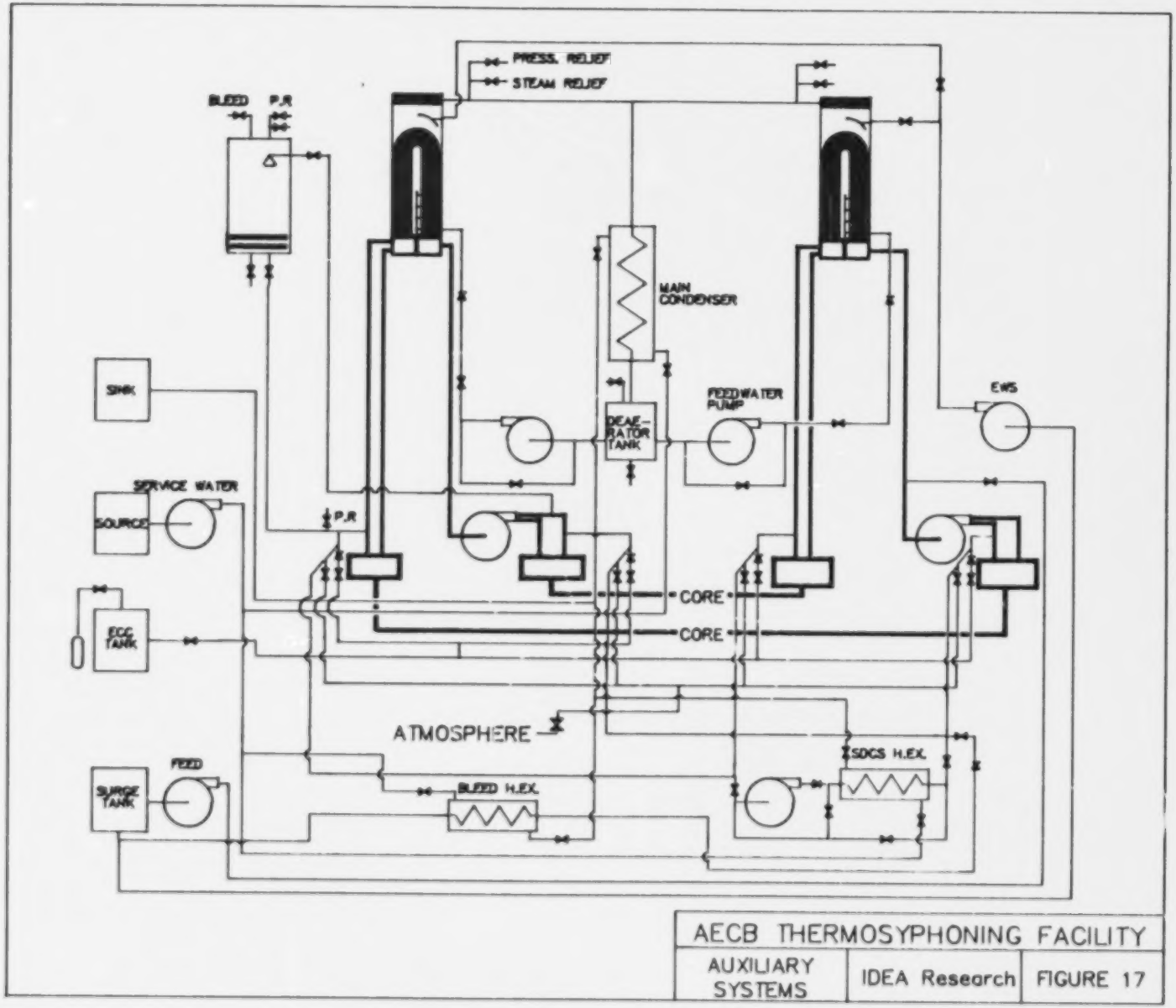
AECB THERMOSYPHONING FACILITY

DEAERATION SYSTEM	DESIGN	IDEA Research
	FIGURE 15	

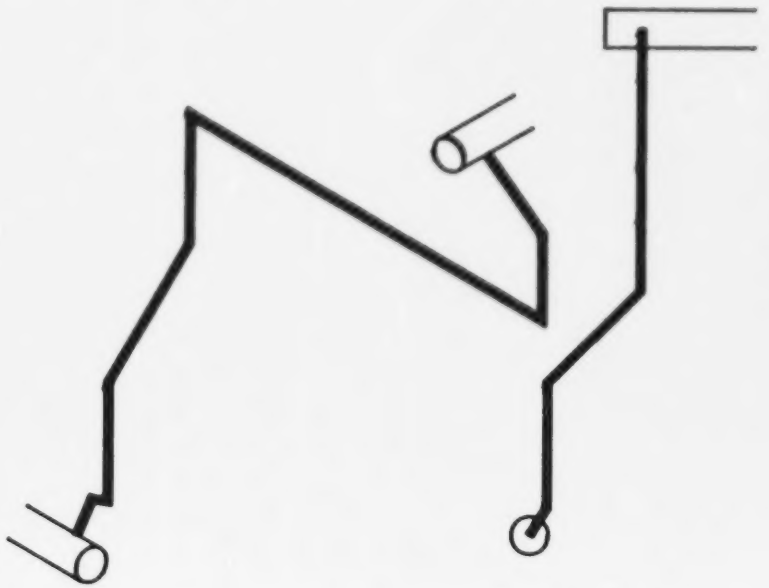


NOTE : POWER REQUIREMENTS AS STATED ARE APPROXIMATE. EXACT REQUIREMENTS WILL BE DETERMINED UPON FINAL DESIGN.

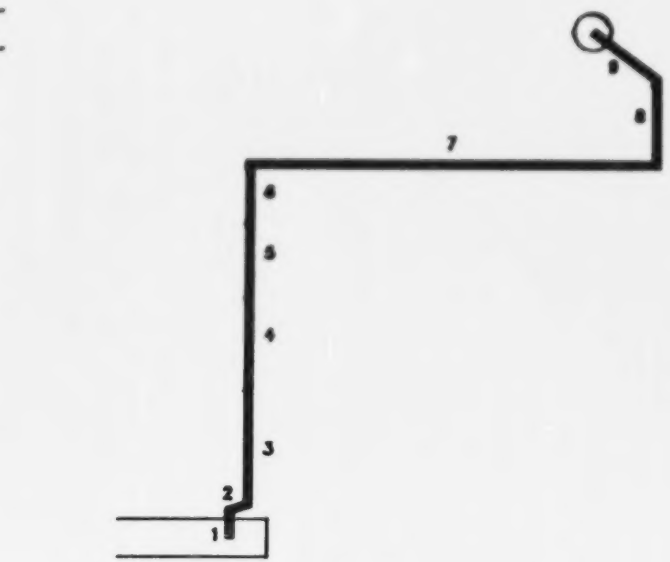
AECB THERMOSYPHONING FACILITY		
BLOCK DIAGRAM OF ELECRIC LOADS	DESIGN	IDEA Research
	FIGURE 16	



AECB THERMOSYPHONING FACILITY		
AUXILIARY SYSTEMS	IDEA Research	FIGURE 17



XYZ ISOMETRIC

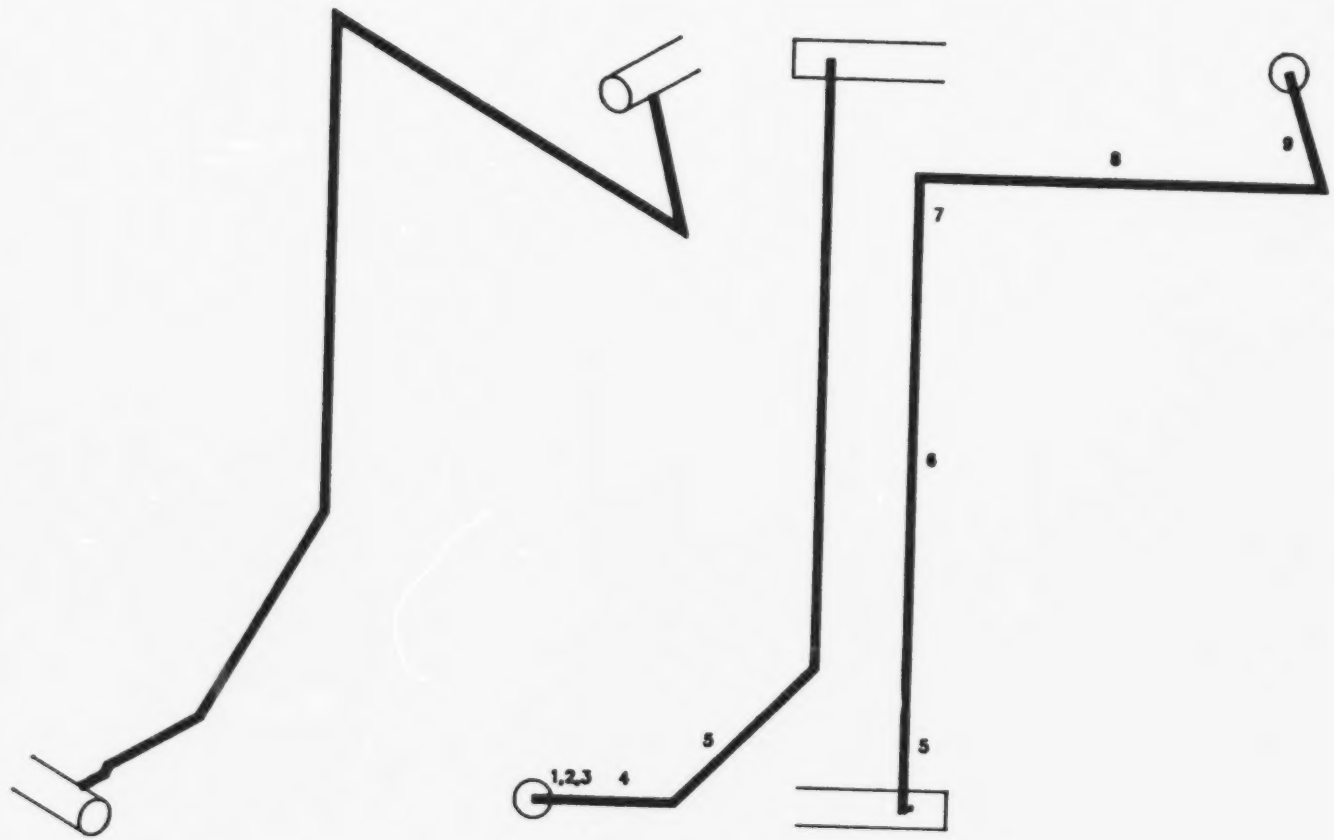


X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A1–1	FIGURE 18	IDEA Research



XYZ ISOMETRIC

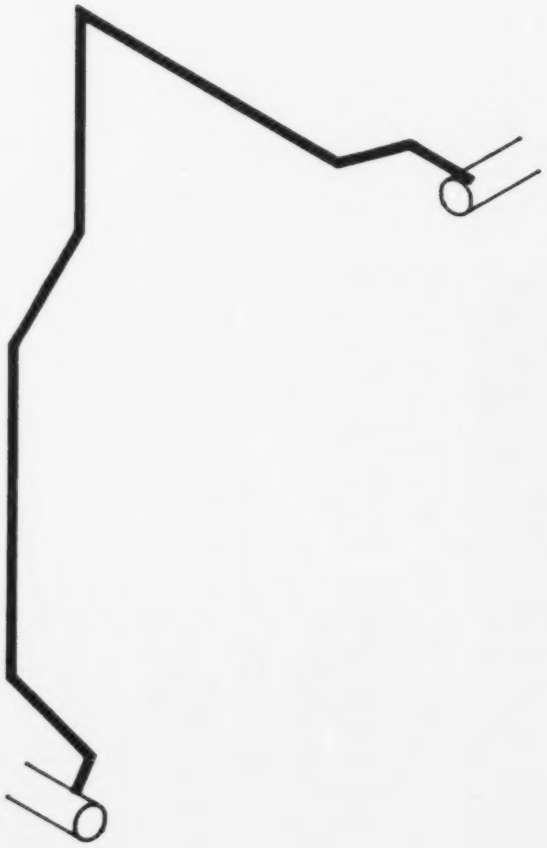
X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

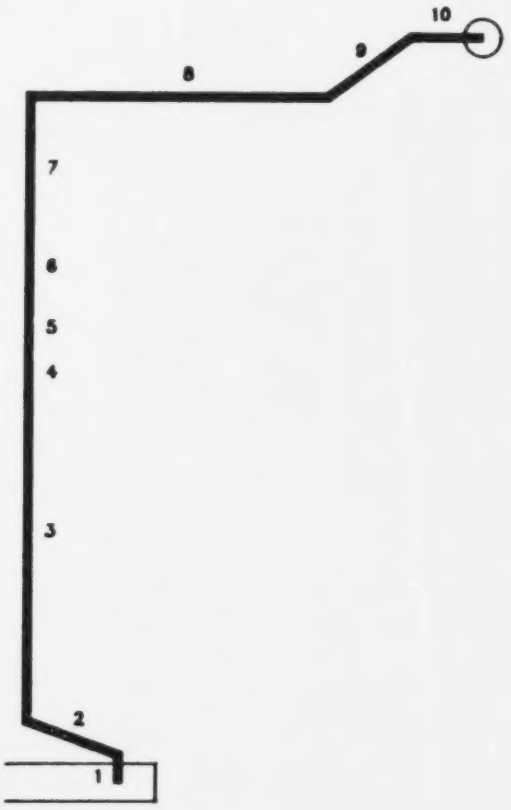
AECB THERMOSYPHONING FACILITY		
FEEDER A2–1	DESIGN	IDEA Research
	FIGURE 19	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS



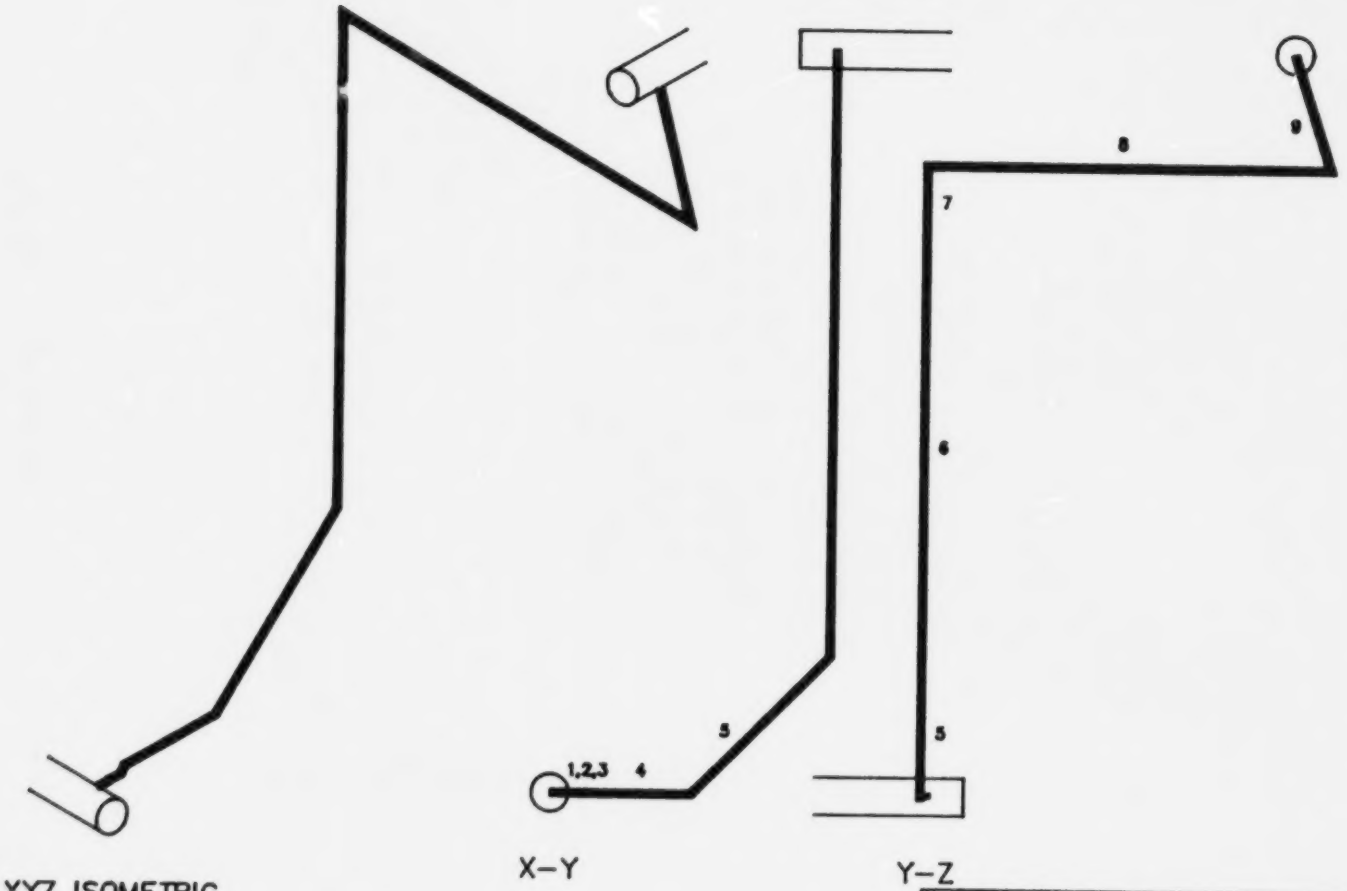
XYZ ISOMETRIC

X–Y



Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A3–1	DESIGN	IDEA Research
	FIGURE 20	

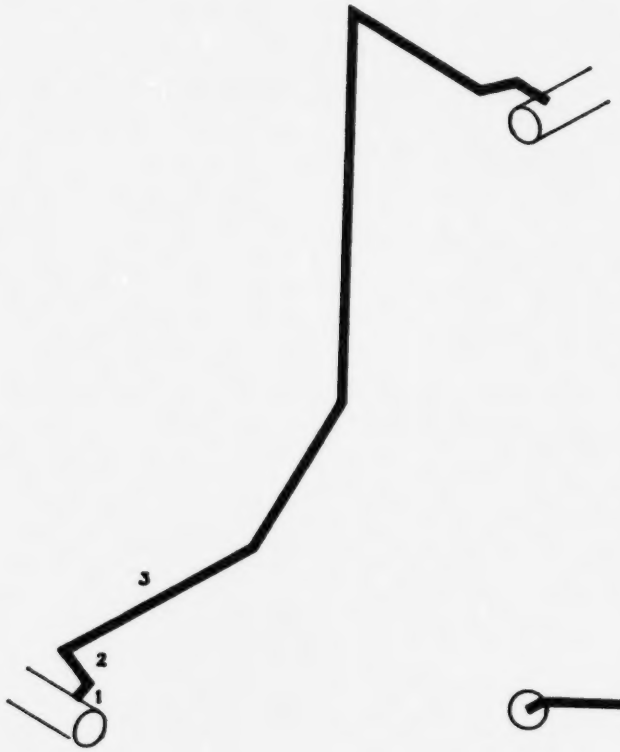


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

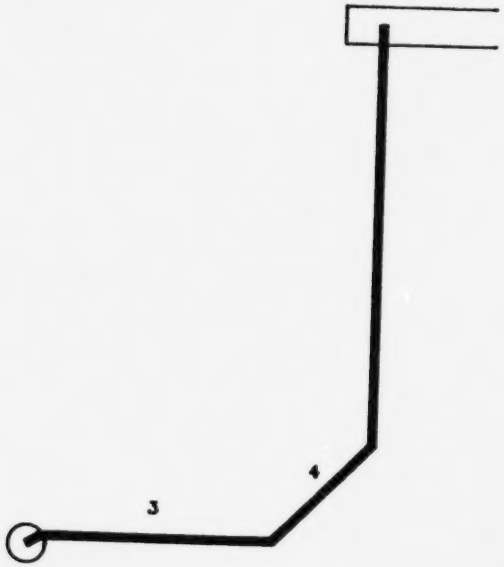
AECB THERMOSYPHONING FACILITY		
FEEDER A4–1	DESIGN	IDEA Research
	FIGURE 21	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

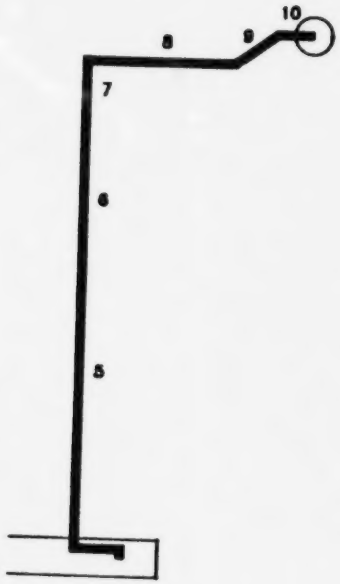
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC

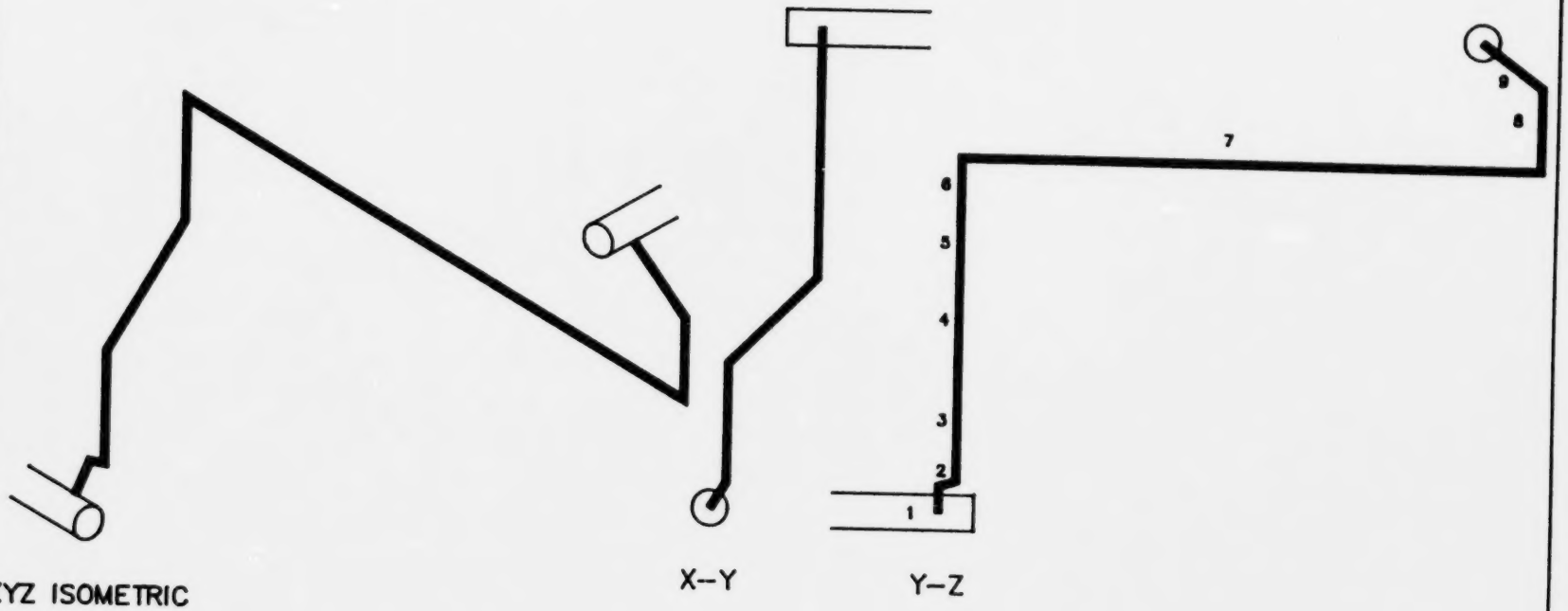


X–Y



Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A5–1	DESIGN	IDEA Research
	FIGURE 22	



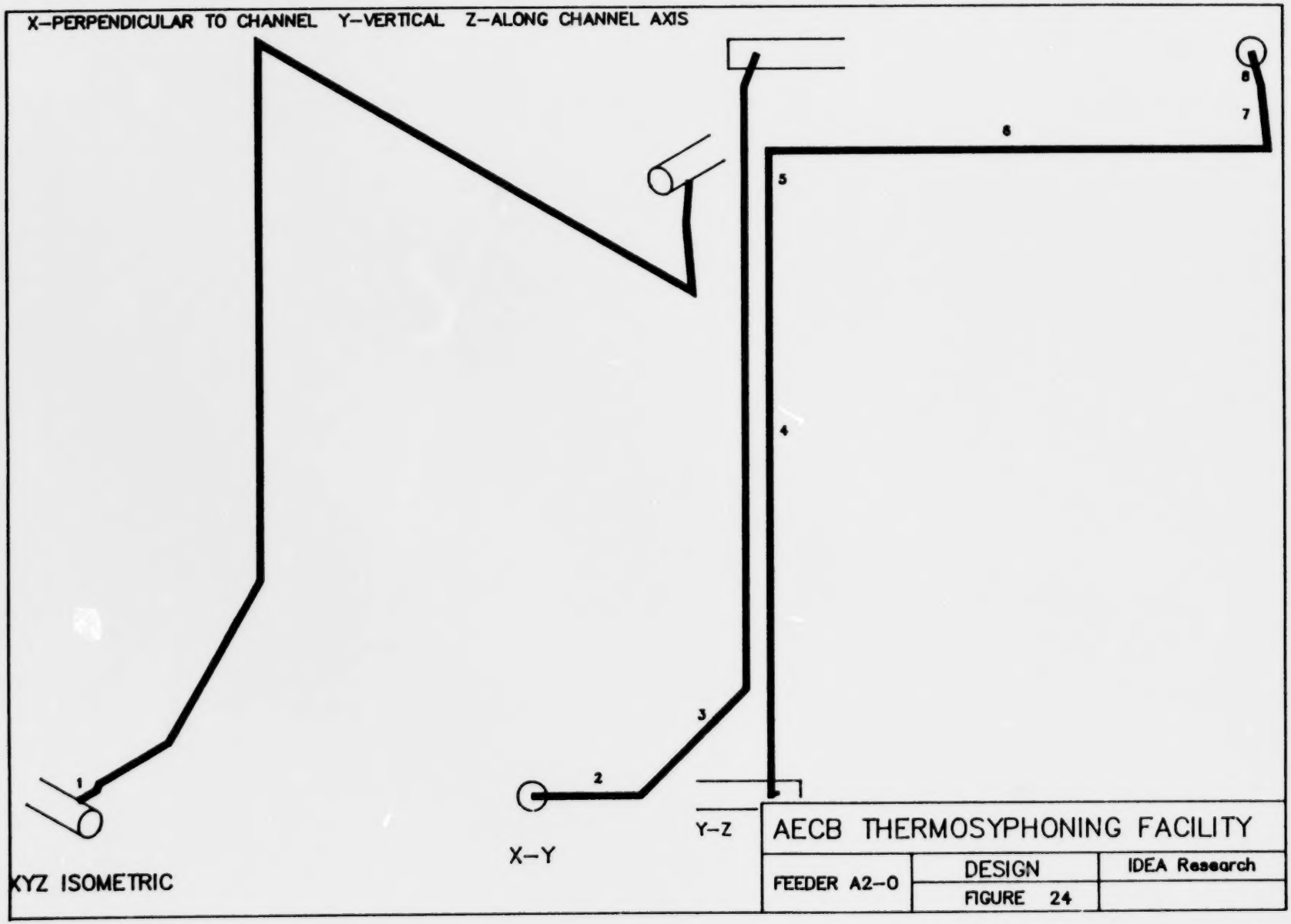
XYZ ISOMETRIC

X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A1–0	FIGURE 23	IDEA Research


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS
1
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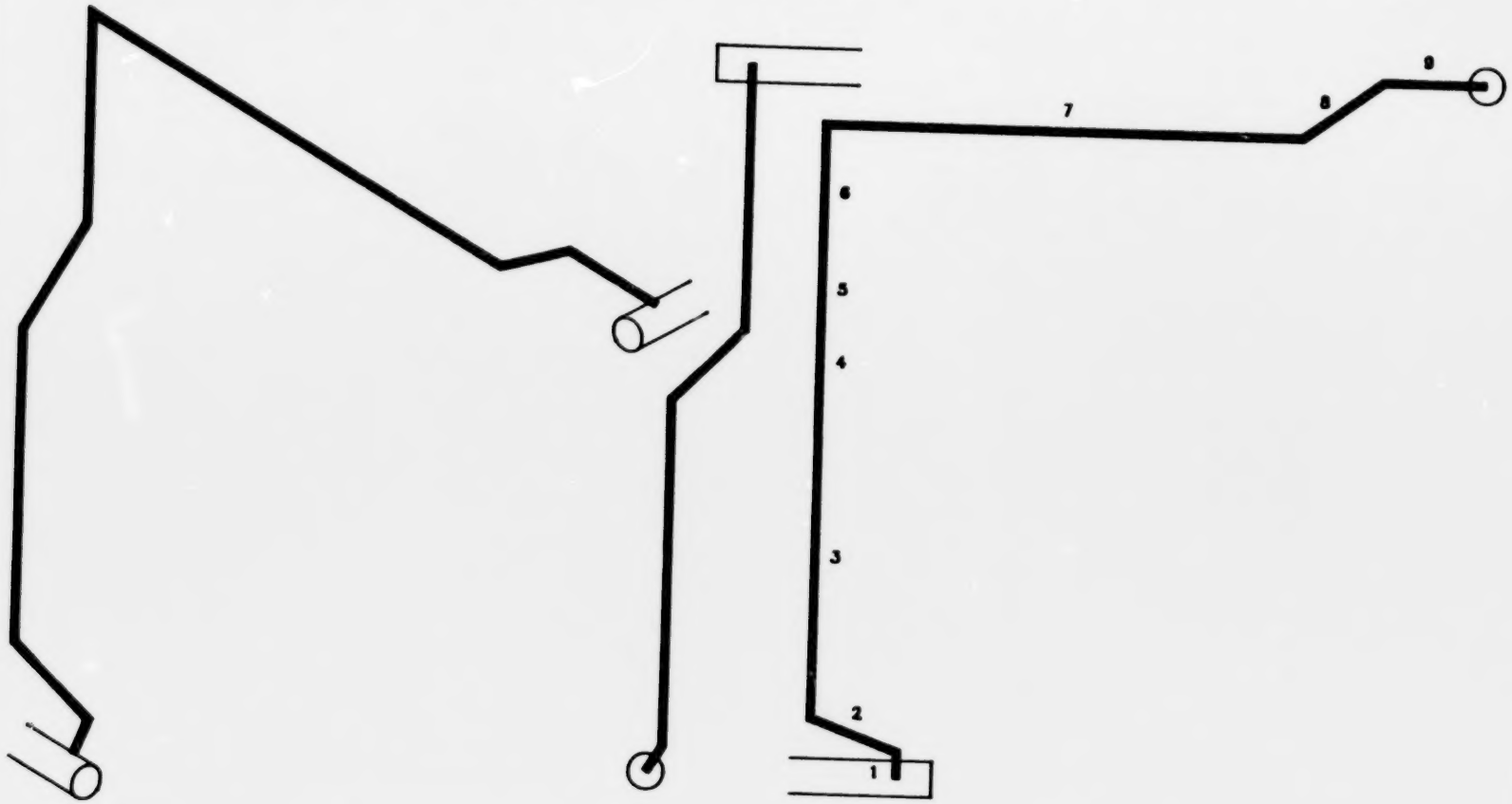
XYZ ISOMETRIC
X–Y
Y–Z
AECB THERMOSYPHONING FACILITY
FEEDER A2–0
DESIGN
FIGURE 24
IDEA Research

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

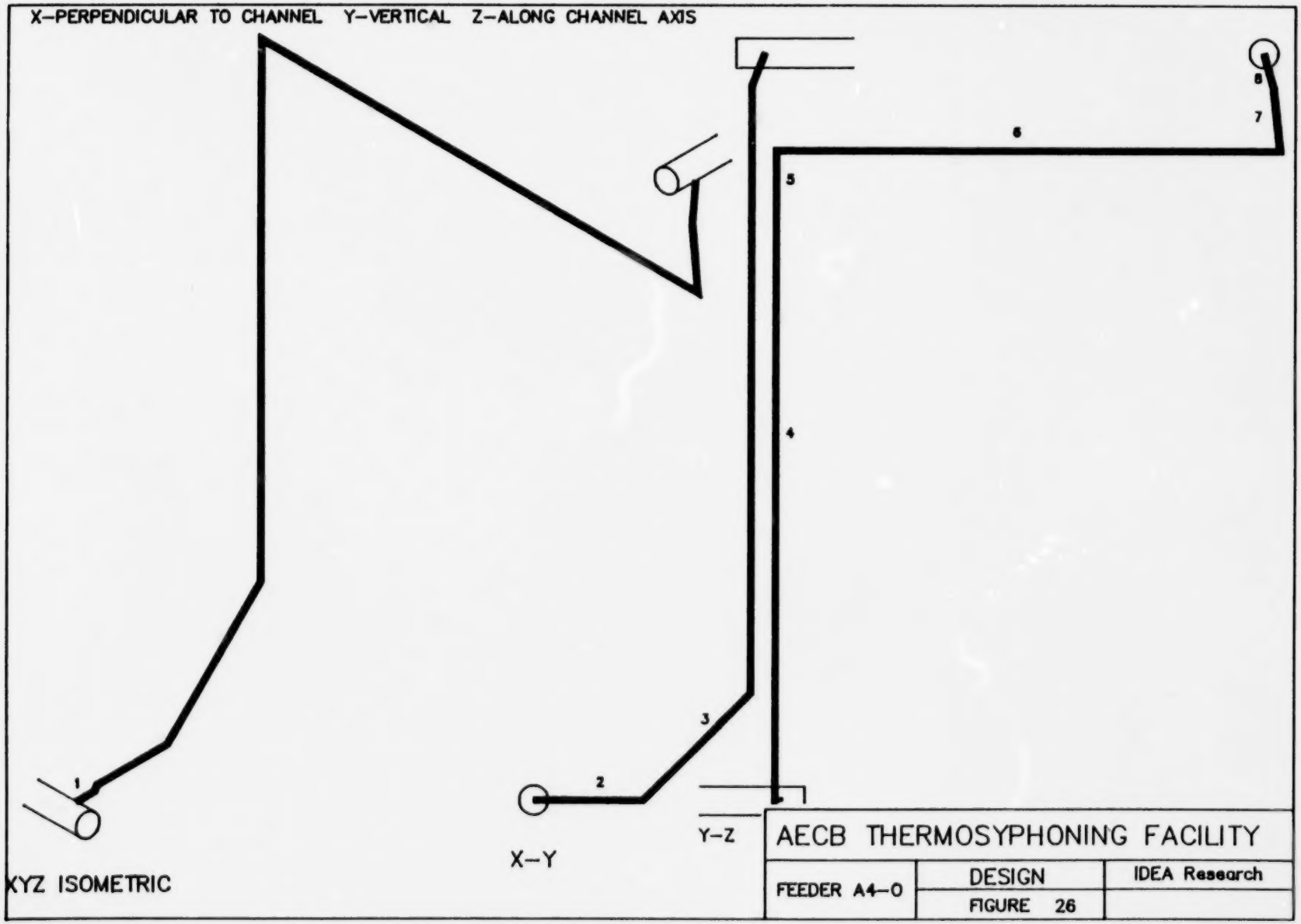


XYZ ISOMETRIC

X–Y

Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A3–0	DESIGN	IDEA Research
	FIGURE 25	


X-PERPENDICULAR TO CHANNEL Y-VERTICAL Z-ALONG CHANNEL AXIS
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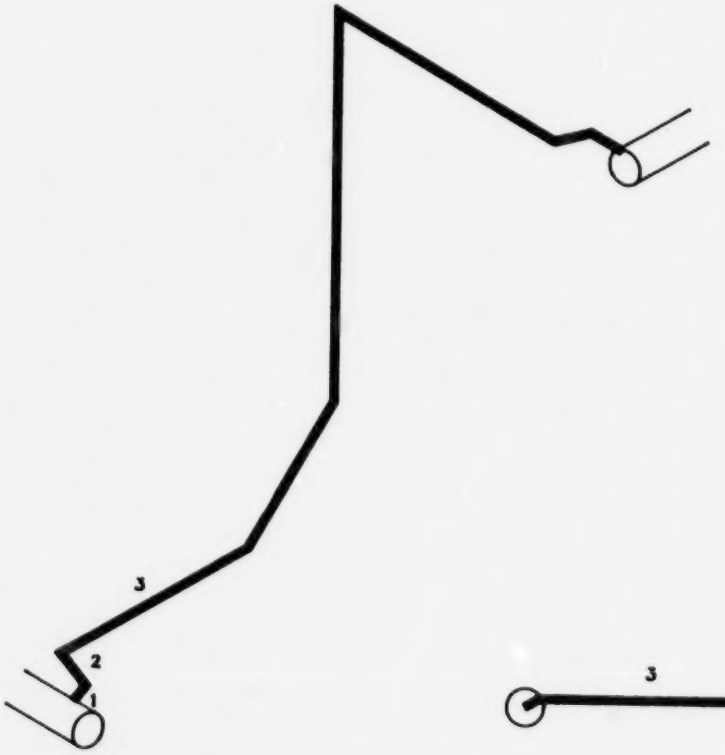
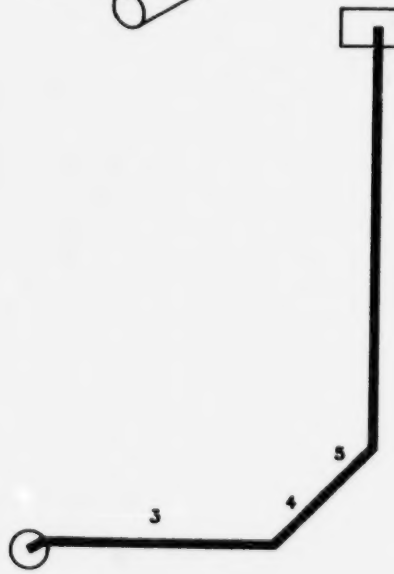
XYZ ISOMETRIC
X-Y
Y-Z
AECB THERMOSYPHONING FACILITY
FEEDER A4-0
DESIGN
IDEA Research
FIGURE 26

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

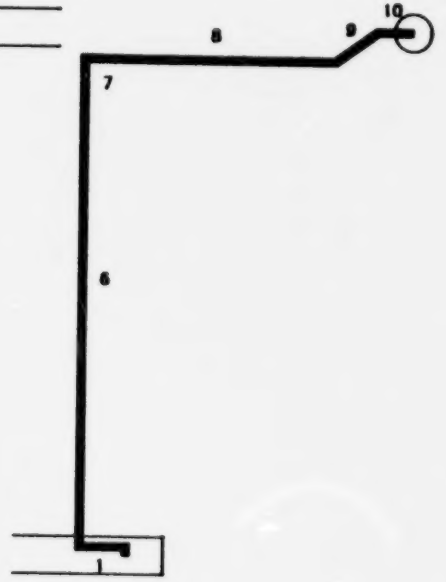
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC

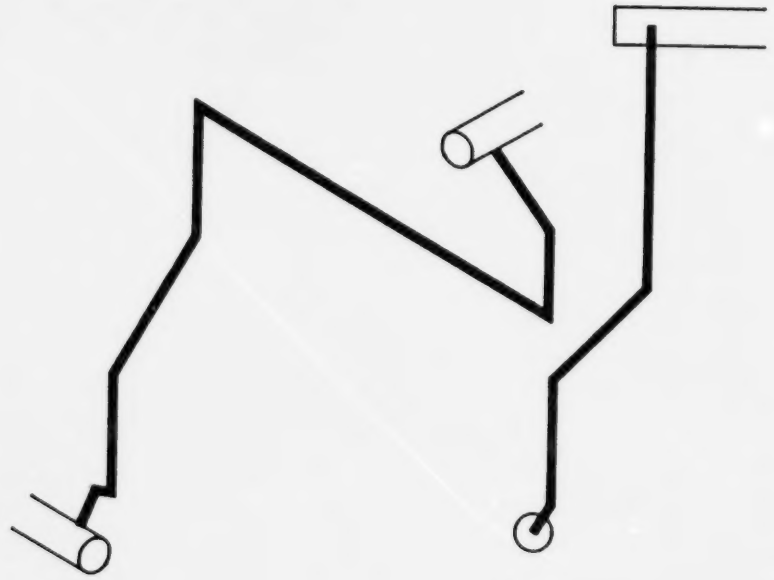


X–Y



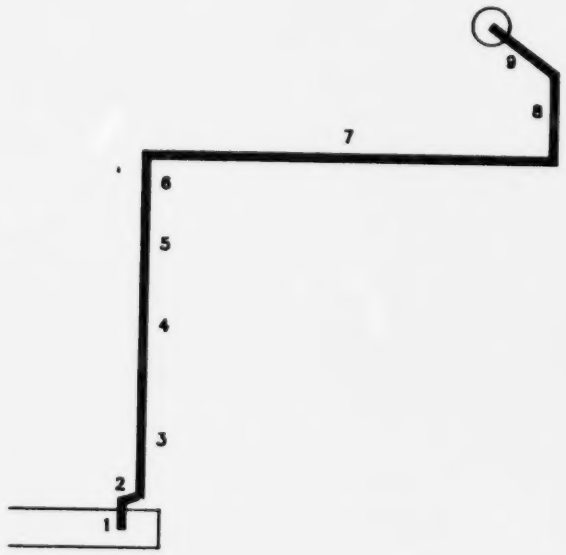
Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A5–0	DESIGN	IDEA Research
	FIGURE 27	



XYZ ISOMETRIC

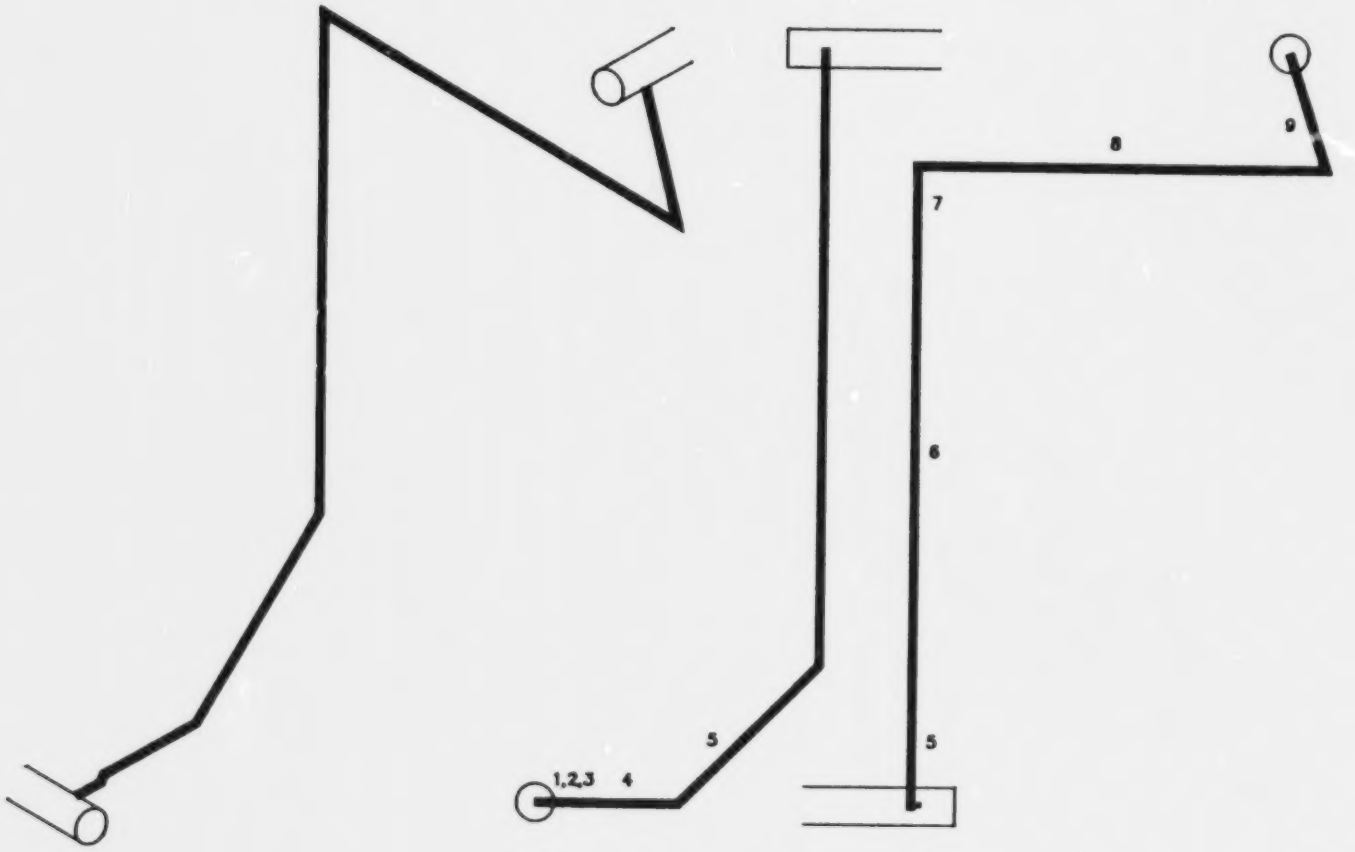
X–Y



Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B1–I		IDEA Research
	FIGURE 28	



XYZ ISOMETRIC

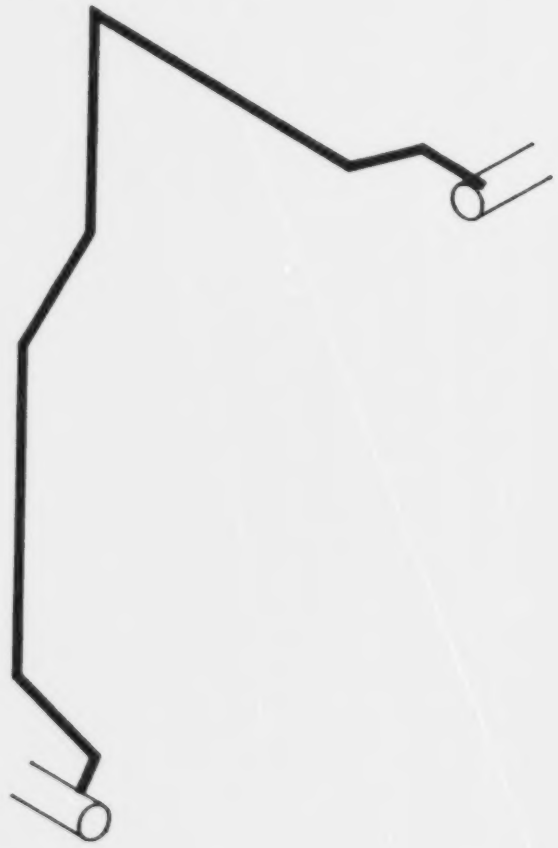
X–Y

Y–Z

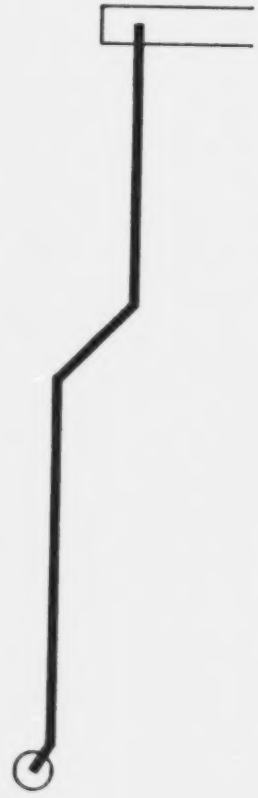
X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B2–I	DESIGN	IDEA Research
	FIGURE 29	

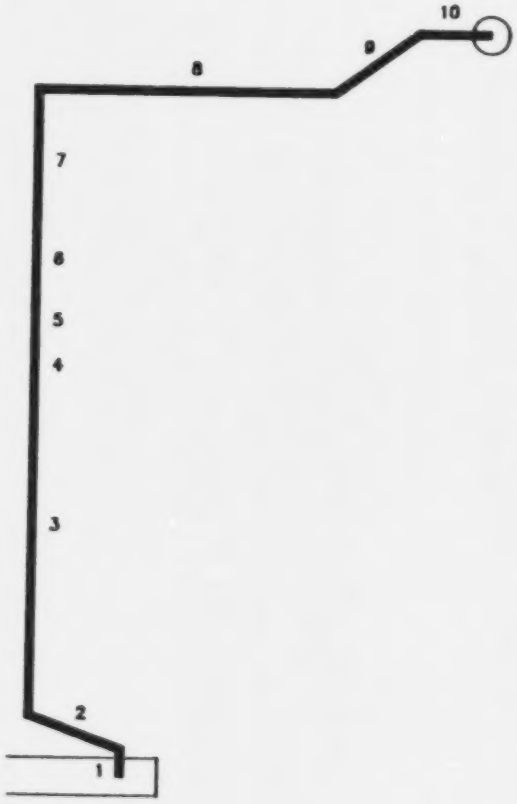
X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS



XYZ ISOMETRIC

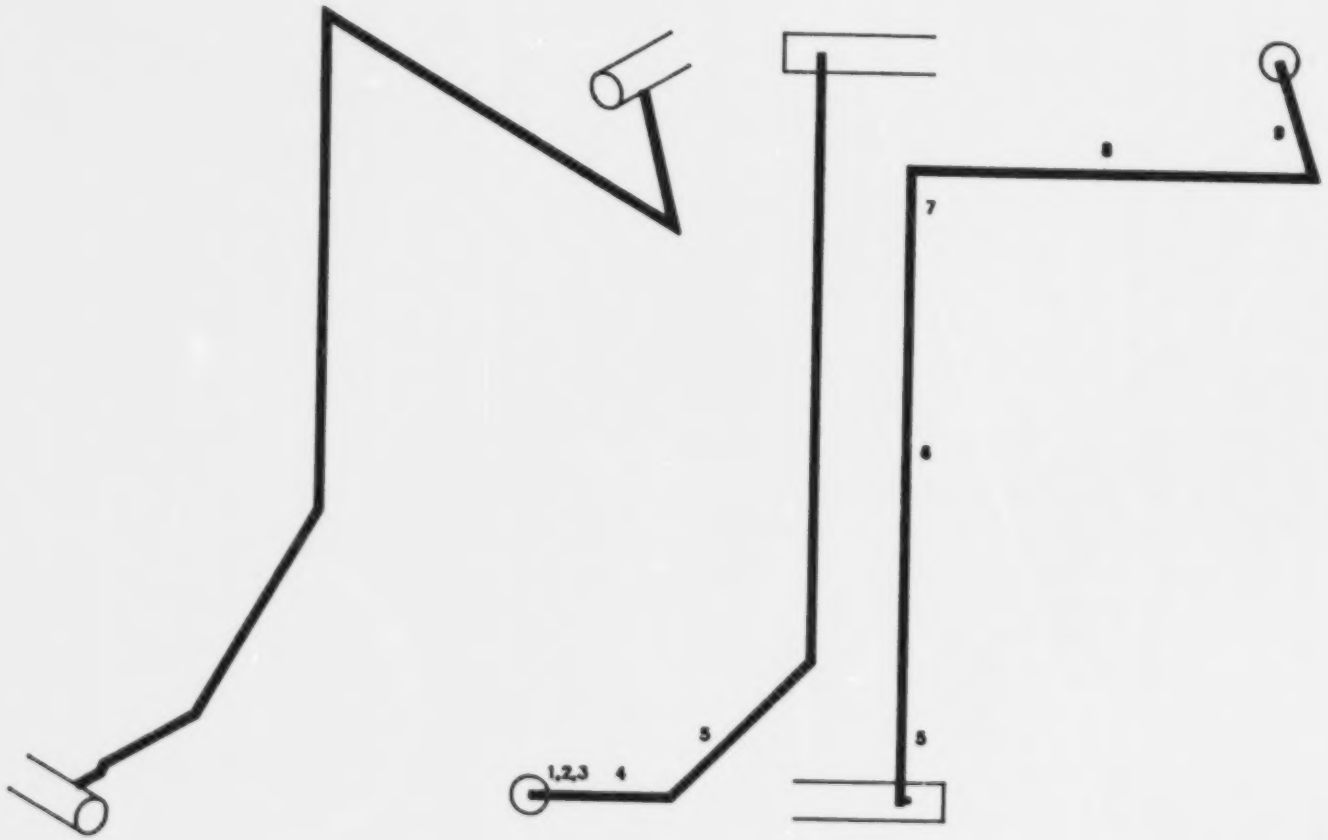


X–Y



Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER B3–1	DESIGN	IDEA Research
	FIGURE 30	

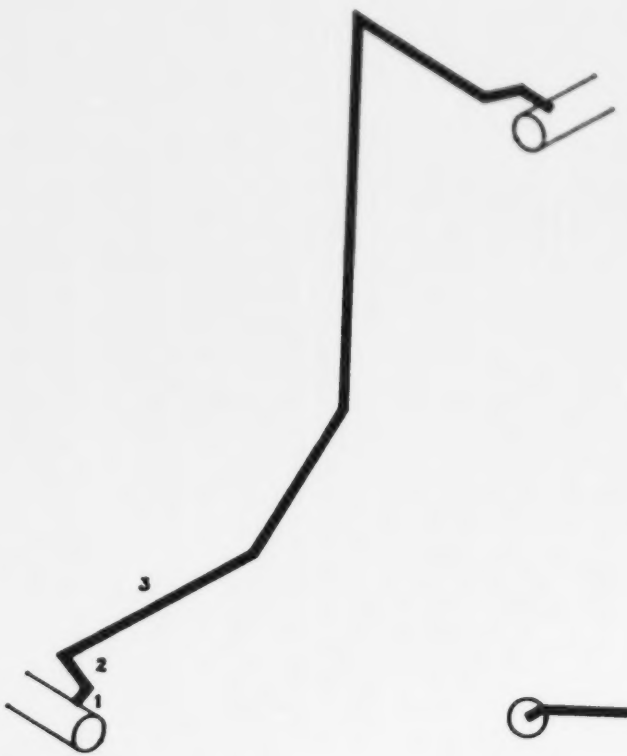


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

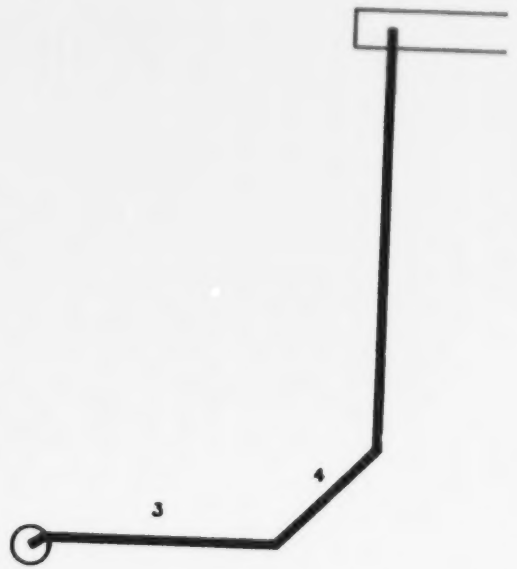
AECB THERMOSYPHONING FACILITY		
FEEDER B4–1	DESIGN	IDEA Research
	FIGURE 31	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



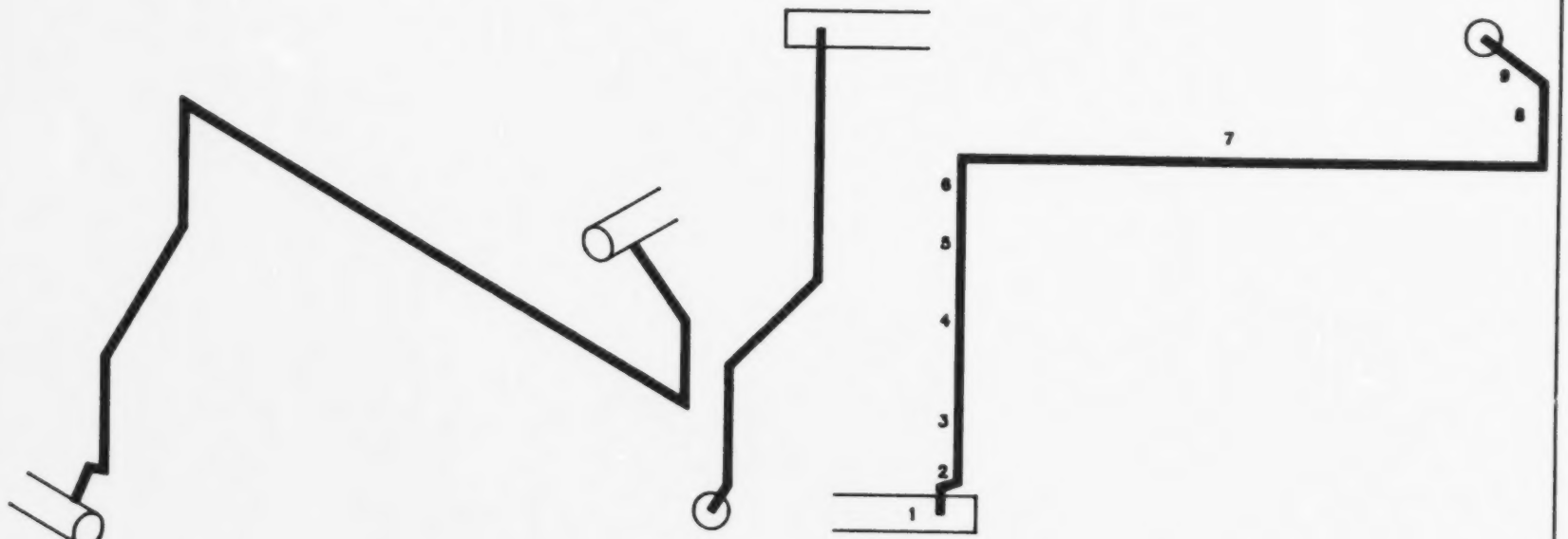
XYZ ISOMETRIC



X–Y

Y–Z

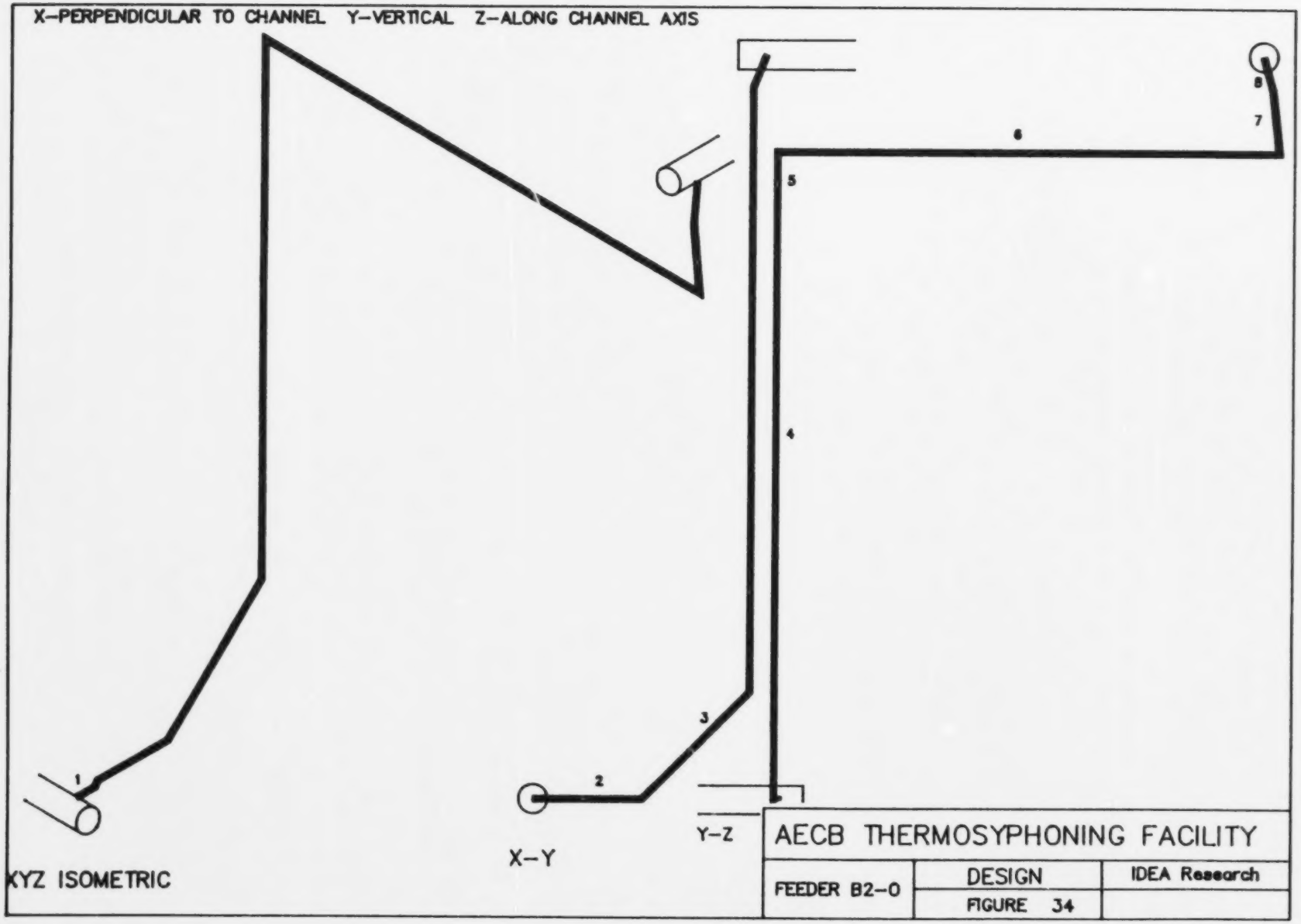
AECB THERMOSYPHONING FACILITY		
FEEDER B5–I	DESIGN	IDEA Research
	FIGURE 32	



X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY

FEEDER B1–0	FIGURE 33	IDEA Research


X-PERPENDICULAR TO CHANNEL Y-VERTICAL Z-ALONG CHANNEL AXIS
1
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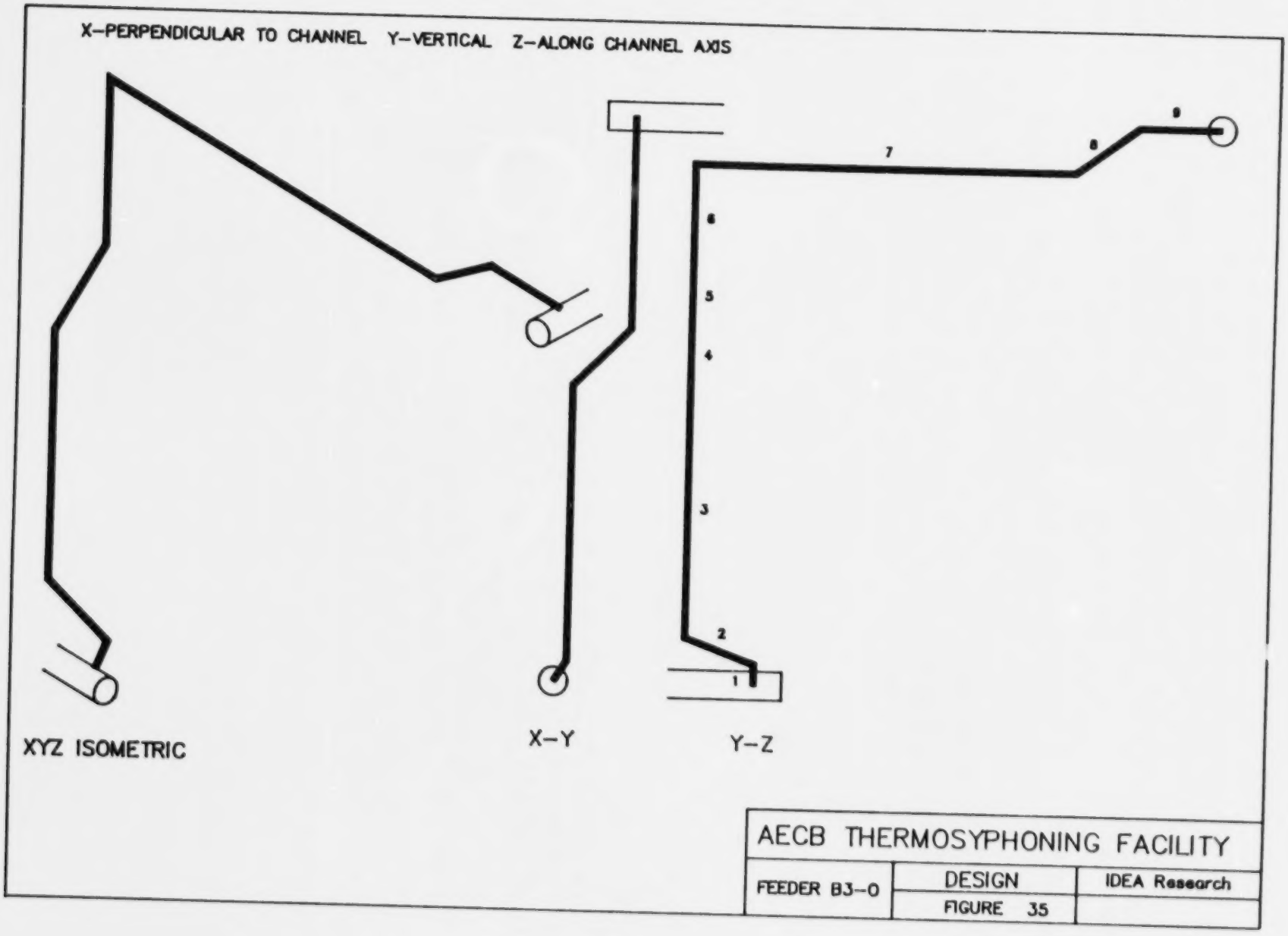
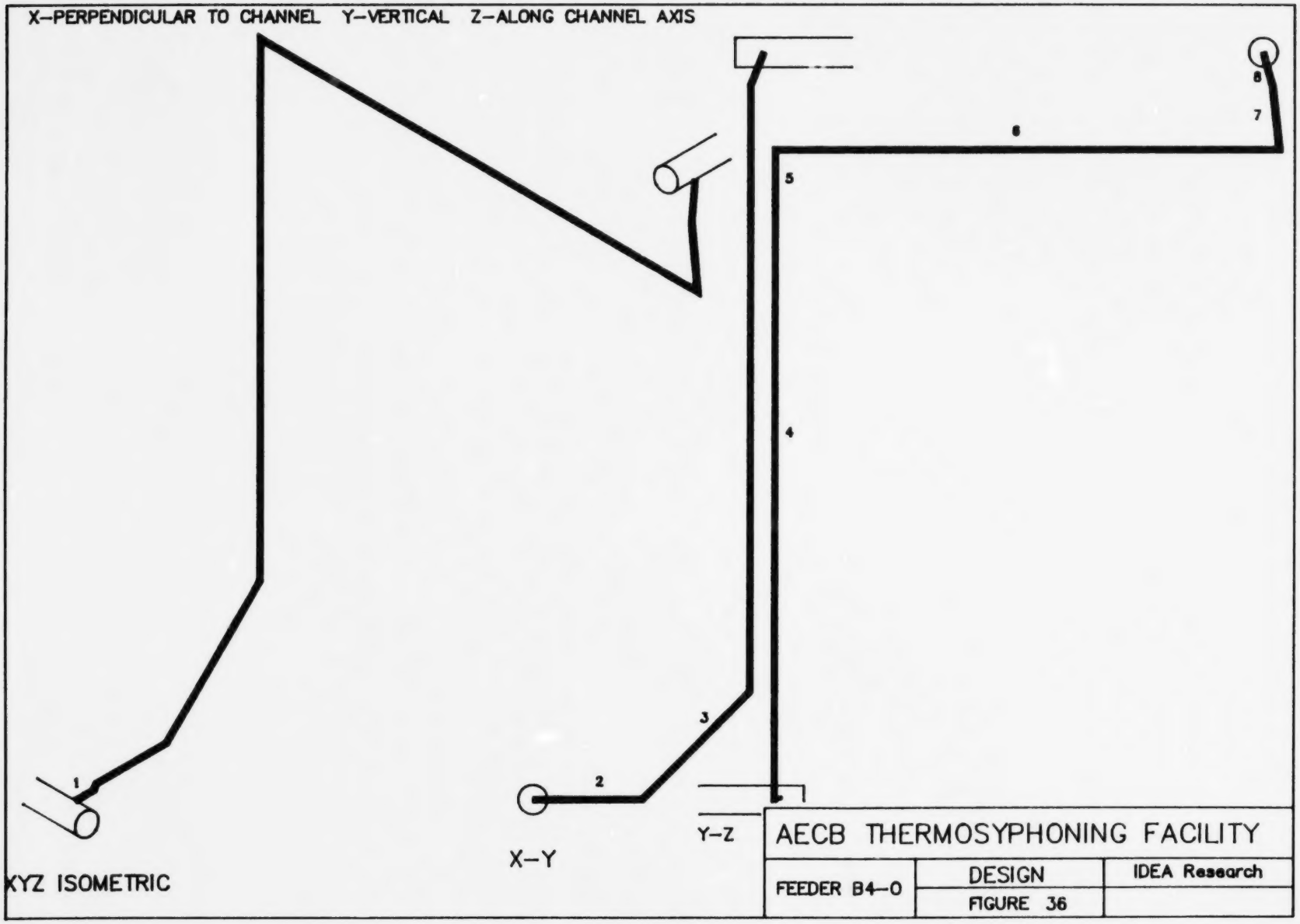
8
XYZ ISOMETRIC
X-Y
Y-Z
AECB THERMOSYPHONING FACILITY
FEEDER B2-0
DESIGN
FIGURE 34
IDEA Research


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS
9
8
7
6
5
4
3
2
1
XYZ ISOMETRIC
X–Y
Y–Z
AECB THERMOSYPHONING FACILITY
FEEDER BJ–0
DESIGN
IDEA Research
FIGURE 35


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS
1
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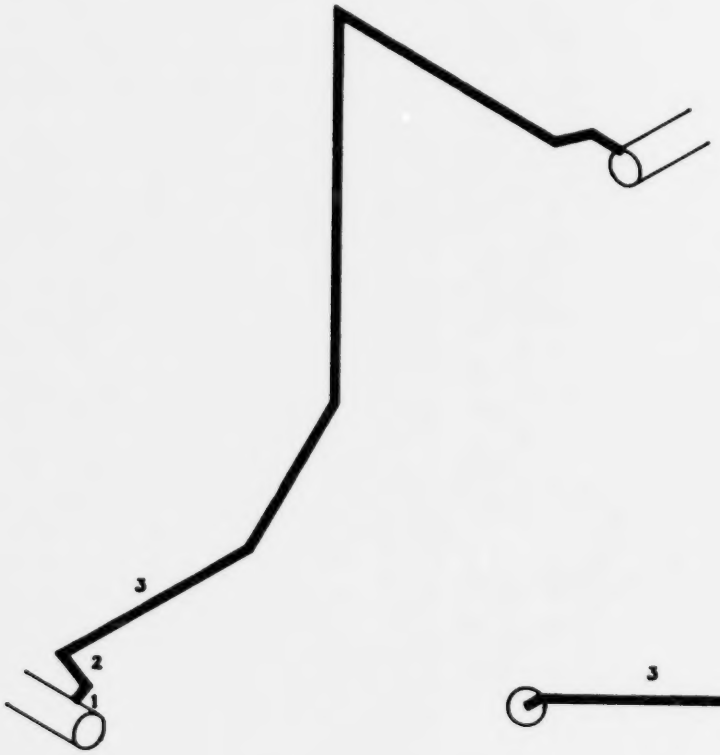
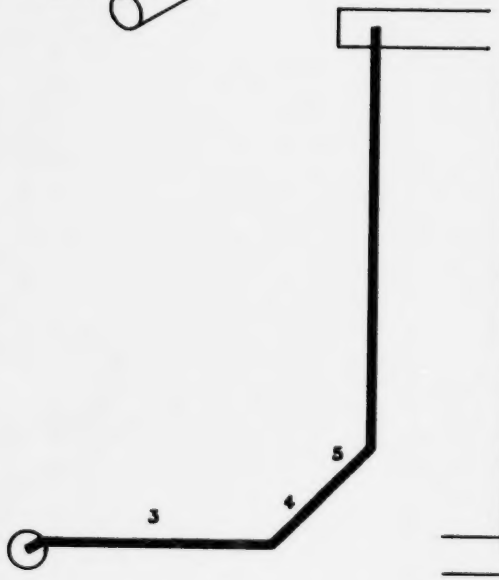
7
8
XYZ ISOMETRIC
X–Y
Y–Z
AECB THERMOSYPHONING FACILITY
FEEDER B4–0
DESIGN
FIGURE 36
IDEA Research

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC



X–Y

Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER B5–0	DESIGN	IDEA Research
	FIGURE 37	

SECTION 3

- THERMOHYDRAULIC ANALYSIS -

A. INTRODUCTION

The geometric data for the thermohydraulic facility has been previously obtained using general two phase scaling laws and Candu specific scaling methodologies developed for this investigation.

The main objective of the thermohydraulic analysis using Atomic Energy of Canada Firebird III computer code is to obtain the steady state characteristics of the facility. The information generated by this steady state analysis can serve as the basis of transient analysis. The following steady state design information is either generated or confirmed.

The pressure distribution in the primary system.

The flow distribution around the loop and amongst various channels.

The pump head.

Fluid enthalpy distribution.

B. MODELLING

The thermosyphoning loop as designed is a scaled down representation of a Candu Primary Heat Transport System. The main geometric features of the Candu are preserved during the scaling down in order to minimise distorsions. The resulting loop is also a geometrically complex system which could not be described as such in the node link representation of FIREBIRD III.

1. Nodalization

The following PHTS components have been nodalized:

1.	Inlet header	(2)
2.	Inlet feeder	(10)
3.	End fitting	(10)
4.	Heated section	(10)
5.	End fitting	(10)
6.	Outlet feeder	(10)
7.	Outlet header	(2)
8.	SG inlet	(2)
9.	Steam Generator	(2)
10.	SG outlet	(2)
11.	Pump	(2)

The figure of eight loop results in 62 different components that must be modelled. Across each of these components the changes in fluid and flow parameters are flow regime dependent.

Depending on flow and channel power some channels may experience boiling in the core section. In order to identify this phenomena the core can be divided into say four parts.

The flow in the end fitting follows a complex geometric path, that would submit to a three section model.

The feeders are typically composed of five sections (horizontal and vertical in different length and diameter).

The headers have a geometry that justifies their division into five sections (feeder connections, SG or pump lines).

The steam generator see drastic changes in the flow regimes and five sections would describe most of them (riser, preheater, bend, vertical sections).

A model based on the above analysis would result in 222 nodes and 254 links. This would require a large amount of computational effort without the guaranty of faithfull representation. In addition a model like that is already outside the range of Firebird III capabilities (maximum number of nodes and links : 250 each).

2. Thermohydraulic Boundary Conditions

The reference Candu pressure and temperature distributions are given in Reference 1. Those are the physical parameters that should be duplicated under identical operating conditions in the facility. The best known values exist for full steady power conditions. Therefore a good agreement on pressure, flows in channels and enthalpy around the system will be the element of check on the scaling methodology and scaled design parameters.

To obtain such information we have chosen to use a 62 node, 70 link representation of the facility. That would give agregate changes across each component but only a few of them can be compared to measured values in the reactor. For example only header to header pressure drops are known and subdistributions in the feeders, end fittings and core are not available as operating data.

The quantities that are available for comparison are:

. Outlet header pressure
. Header to header pressure drop
. Core power
. Steam generator power
. Outlet header temperature.
. Inlet header temperature.
. Channel flows (design information)

The 62 node, 70 link model shown in Figure 1 can provide information for comparison to the above parameters.

3. Node and Link Data

The node and link geometric and hydraulic data for both passes are equivalent and are listed in Appendix A.

The modelling decisions of interest are described below:

1. The headers are modelled as single volumes and the dual discharge or inlet pipes are lumped into one single pipe conserving hydraulic diameters.

2. The feeders are modelled as vertical pipes preserving their length and distributed loss coefficients. In channels A-1 and B-1 the orifices are modelled as distributed loss coefficient.

3. The end fittings are modelled as flow pipes with a hydraulic diameter equal to the annulus hydraulic diameter. The liner tube resistance is lumped with the inlet and outlet loss coefficients.

4. The heated sections representing the core include the loss coefficients due to the spacers.

5. The steam generator plenum includes the volume of the connecting pipes.

6. The steam generator tubes are modelled as two vertical sections and a loss coeficient for the bend and inlet and outlet is included.

7. The secondary side of the steam generator is modelled as a constant temperature heat sink that balances the heat generated in the core. Consequently no heat losses are assumed to occur in the loop.

The typical loss coefficients used are as follows:

1.	Bend :	0.9
2.	Entrance :	1.
3.	Exit :	1.
4.	End fitting :	3.
5.	Core :	6.
6.	Orifice :	13.

C. RESULTS

1. Reference Case Parameters

The parameters of interest for comparison with the scaled calculated facility parameters and their corresponding value in the Candu are listed below :

. Outlet header pressure	9.99	MPa
. Header to header pressure drop	1.25	MPa
. Core power (100 %)	2056	MW
. Steam generator power	2064	MW
. Outlet header temperature	310	°C
. Inlet header temperature	266	°C
. Total loop flow	1900	kg/s
. Channel flows (design information)		
Channel C-09	19.0	kg/s
Channel K-09	23.8	kg/s
Channel Q-02*	17.3	kg/s
Channel T-12	24.4	kg/s

* modified to the elevation of K.

2. Scaled Reference Case

Following our scaling methodology and the subsequently determined scaling ratios the corresponding parameter values for the facility have been determined as follows.

Facility power = Candu power x 10/380 x area ratio x lenyth ratio x power ratio

Facility channel flow = Candu channel flow x area ratio x velocity ratio

Facility total flow = Candu total flow x area ratio x velocity ratio x 10/190

Facility channel power = 6.5 MW normalised for flow ratios with channel A-5

The resulting target values are as follows :

. Outlet header pressure	9.99	MPa
. Header to header pressure drop	1.25	MPa
. Core power (100 %)	7.491	MW
. Steam generator power	7.491	MW
. Outlet header temperature	310	°C
. Inlet header temperature	266	°C
. Total loop flow	13.8	kg/s
. Channel flows		
Channels A-1 , B-1	2.63	kg/s
Channels A-3 , B-3	3.32	kg/s
Channels A-2 , A-4 , B-2 , B-4	2.40	kg/s
Channels A-5 , B-5	3.36	kg/s

3. Thermohydraulic Facility Parameters

The results for the steady state calculations with the facility at 100% full power using Firebird III are shown below.

. Outlet header pressure	9.99	MPa
. Header to header pressure drop	1.21	MPa
. Core power (100 %)	7.491	MW
. Steam generator power	7.491	MW
. Outlet header temperature	311	°C
. Inlet header temperature	272	°C
. Total loop flow	14.3	kg/s
. Channel flows		
Channels A-1 , B-1	2.86	kg/s
Channels A-3 , B-3	3.48	kg/s
Channels A-2 , A-4 , B-2 , B-4	2.26	kg/s
Channels A-5 , B-5	3.37	kg/s

Figure 2 shows the pressure distribution in the two passes of the facility.

Figure 3 shows the flow distribution in the two passes of the facility.

Figure 4 shows the temperature distribution in the two passes of the facility.

Table 1 shows the Candu scaled flow and the flows calculated by Firebird III.

D. CONCLUSIONS

As shown above in the figures and table the flow distribution as calculated by Firebird III are in very good agreement with the expected flows predicted by the scaling. The pressure distribution around the system matches the pressure distribution in the Candu. The enthalpy distribution and channel power distribution are such as to provide the same quality in the outlet header as expected during normal full power operation.

It is therefore concluded that the scaling done to generate geometric and thermohydraulic parameters for the facility is appropriate and represents adequately a Candu 600 primary heat transport system.

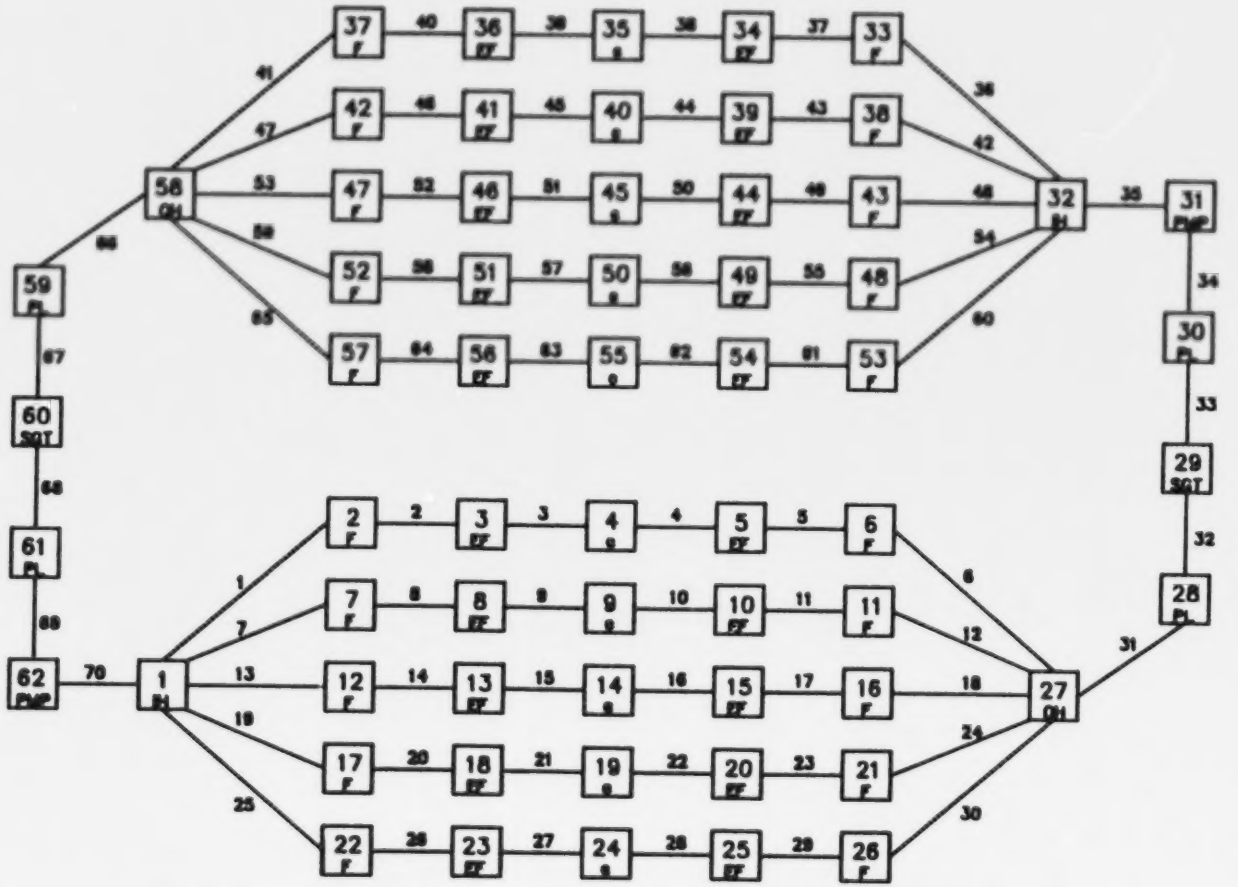
E. REFERENCES

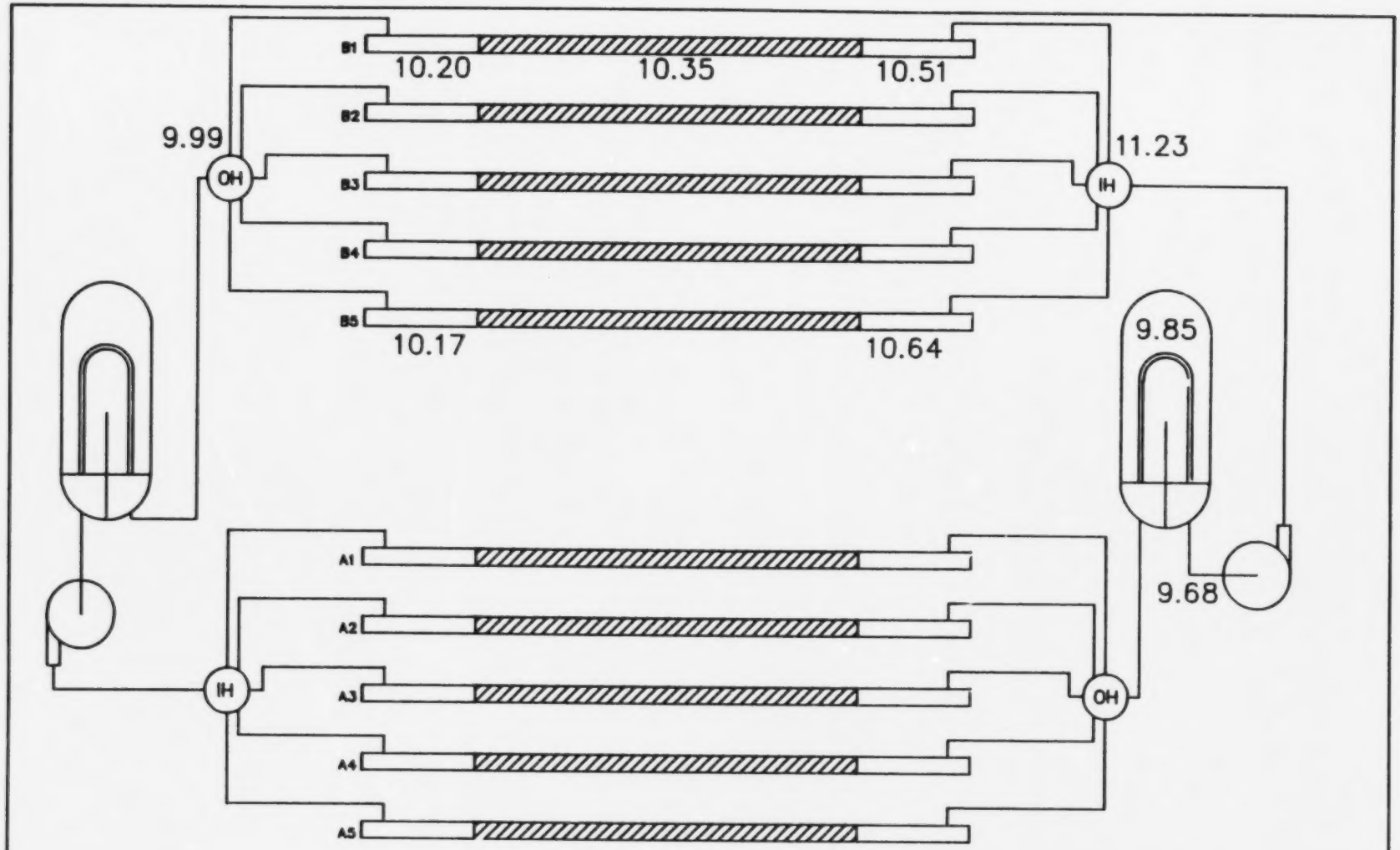
1. Jean-Claude Amrouni and Sunil Nijhawan, "Candu-600 Thermohydraulics Data for a Thermosyphoning Rig", IDEA-07, August 1984.

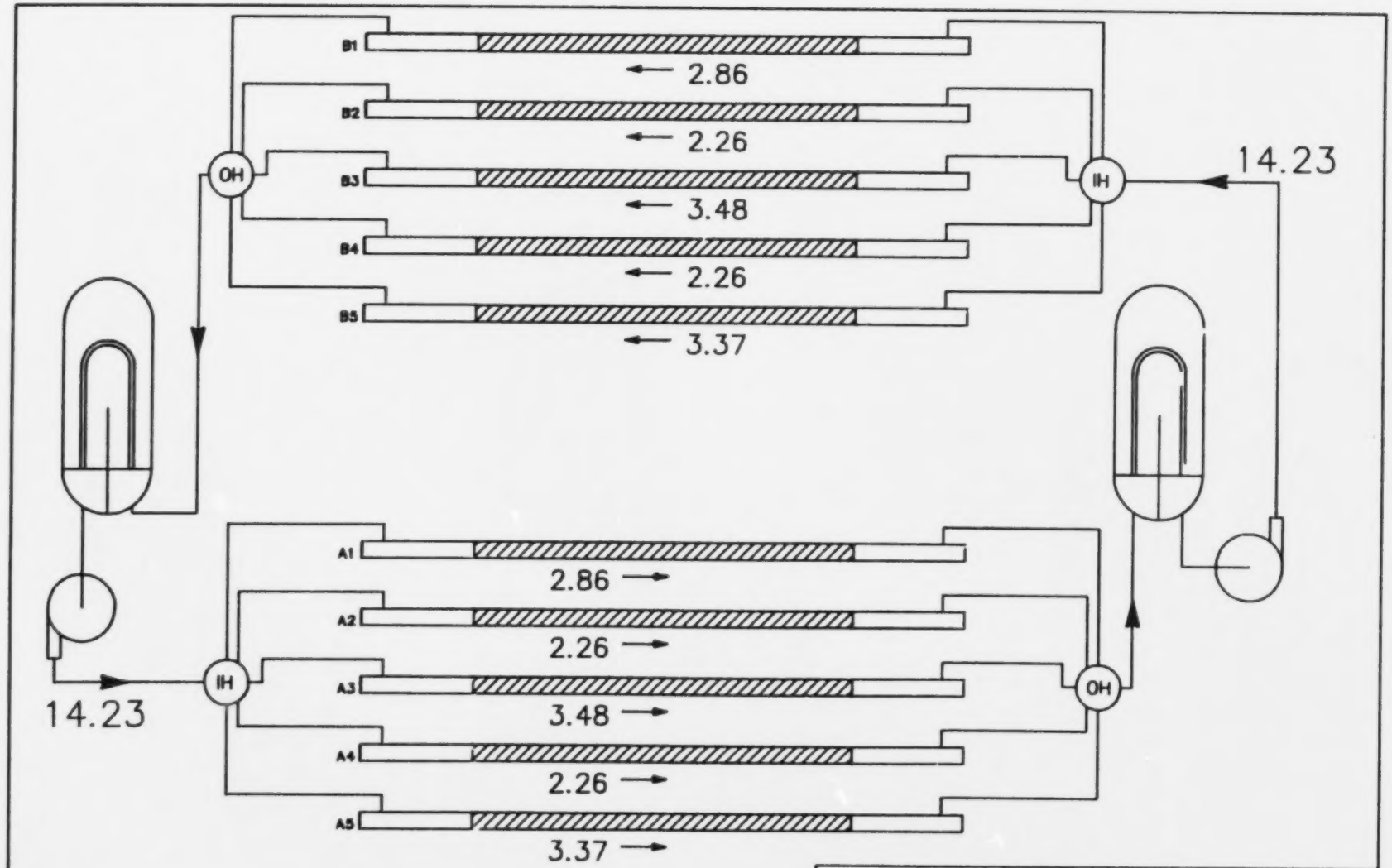
Table 1

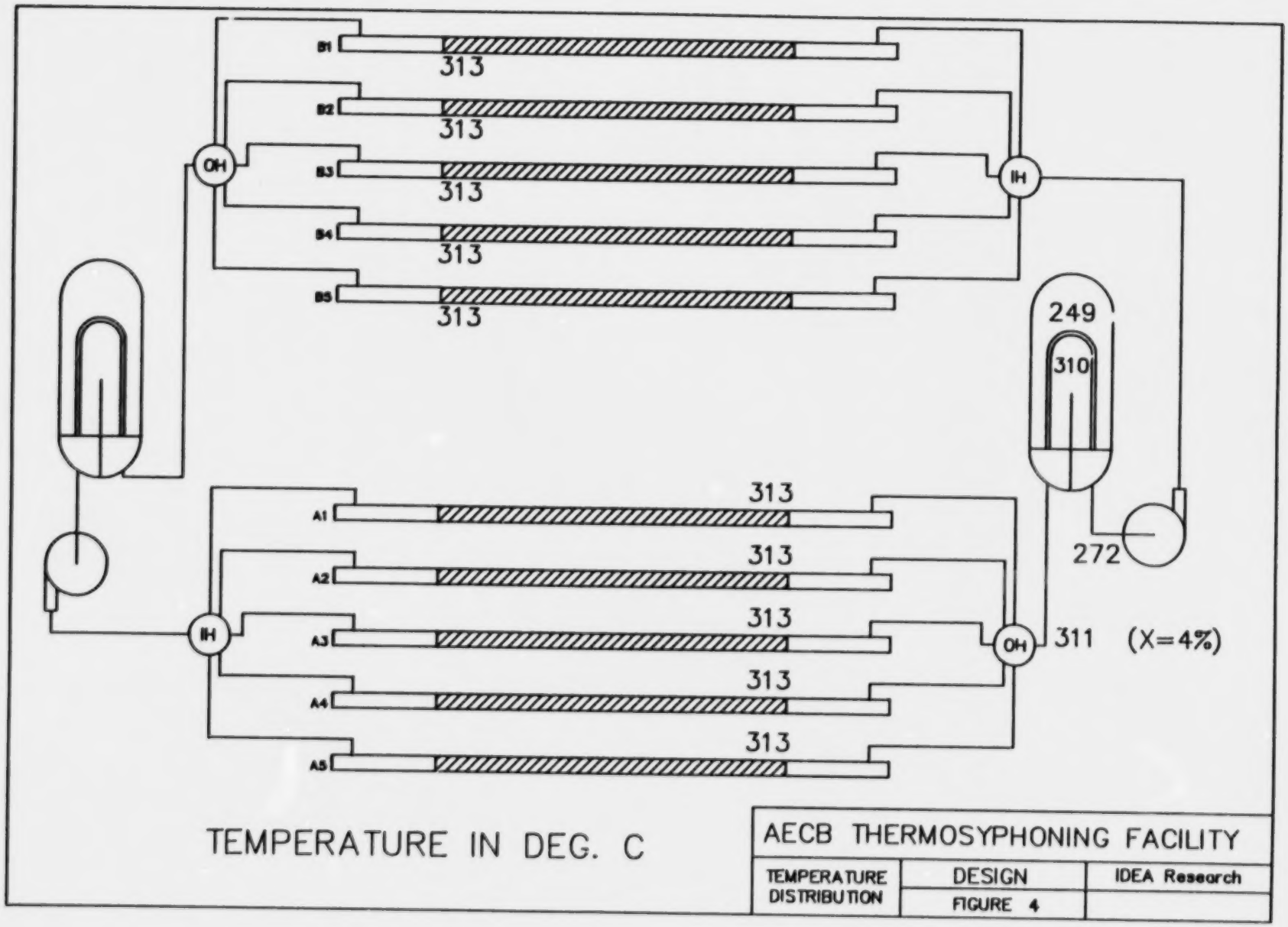
Facility and Candu Flows

Channel	Expected kg/s	Calculated kg/s	(C-E)/C %
A-1	2.63	2.86	8
A-2	2.40	2.26	-6
A-3	3.32	3.48	5
A-4	2.40	2.26	-6
A-5	3.36	3.37	0
B-1	2.63	2.86	8
B-2	2.40	2.26	-6
B-3	3.32	3.48	5
B-4	2.40	2.26	-6
B-5	3.36	3.37	0
Total core	13.8	14.3	3


AECB THERMOSYPHONING FACILITY
FIREBIRD NODALISATION
DESIGN
FIGURE 1
Idea Research


B1
B2
B3
B4
B5
10.20
10.35
10.51
9.99
OH
11.23
IH
10.17
10.64
9.85
9.68
A1
A2
A3
A4
A5
IH
OH
PRESSURE IN MPa
AECB THERMOSYPHONING FACILITY
PRESSURE DISTRIBUTION
DESIGN
FIGURE 2
IDEA Research


B1
2.86
B2
2.26
OH
B3
3.48
IH
14.23
B4
2.26
B5
3.37
A1
2.86
A2
2.26
IH
A3
3.48
OH
14.23
A4
2.26
A5
3.37
FLOW IN kg/s
AECB THERMOSYPHONING FACILITY
FLOW DISTRIBUTION
DESIGN
FIGURE 3
IDEA Research


B1
313
B2
313
OH
B3
313
IH
B4
313
B5
313
249
310
313
A1
313
A2
313
IH
A3
OH
311 (X=4%)
313
A4
313
A5
272
TEMPERATURE IN DEG. C
AECB THERMOSYPHONING FACILITY
TEMPERATURE DISTRIBUTION
DESIGN
IDEA Research
FIGURE 4

SECTION 4

- INSTRUMENTATION -

A. INTRODUCTION

Proper choice of instrumentation is important if meaningful, valid and relevant data, that adequately and faithfully represent the phenomena of interest, are to be obtained from an experimental facility. It is essential that instrumentation itself does not distort the behaviour of the system. An optimisation process was undertaken with the following guidelines :

1. What needs to be determined to specify the steady state of the system.
2. What phenomena need to be identified either quantitatively or qualitatively once the system undergoes a predetermined transient.
3. Which quantities need to be measured for safe operation of the system.
4. Cost of instrumentation and cost of scanning, storage and reduction and analysis of data thereof.
5. Inherent inaccuracies of various types of instrumentation.

The core, component and system instrumentation are designed to quantify the independent variables (power, temperature, flows, pressure), dependent variables (pressure, flows, temperature, flow regimes), the system characteristics (heat losses, hydraulic loss coefficient) and the safety and control characteristics of the facility. It is important that the data include inherent and operational error bands.

Figure 1, 2 and 3 show the instrumentation that is necessary for the facility.

B. DESIGN CRITERIA

Instrumentation for the thermosyphoning facility should be designed so that the following objectives can be met :

i) Perform mass, momentum and energy balance across each major component under steady state conditions. This tranlates into determining flow rates, hydraulic loss coefficient, flow regimes, power input, heat losses, heat up rates for core and system, liquid, vapor and gas inventories. Some of these are necessary for operation, safety and control while others are necessary so that data can be used for code development and verification.
ii) Identify cooling modes and their breakdown during natural circulation.
iii) Determine the thermosyphoning flow rates as a function of independent variables like power, pressure, pump rundown and timing of start of rundown.
iv) Determine wether nonequilibrium exists in the core and the steam generators.
v) Investigate the stability of thermosyphoning flows in single and two phase conditions and the parameters that influence the breakdown and transition.

vi) Identify channel to channel interactions.
vii) Quantify the secondary side heat sink capabilities and limitations, dictated for example by the primary side tube flooding under reflux condensation.
viii) Quantify liquid holdup rates in the steam generators under reflux condensation.
ix) Quantify fuel heatup rates.
x) Provide data for control.
xi) Provide data for safety trips.
xii) Provide data for display.

C. GENERAL INSTRUMENTATION DESCRIPTION

During steady state and experimental transients, power, temperature, differential and absolute pressures, water levels, flows and voids should be measured in the primary, secondary and auxiliary systems.

Power can be measured by Hall-effect watt transducers. The transducers consist of donought armatures, stepdown current and voltage transformers and rectifiers to provide millivolt output to scanners. Power is measured in the channels and in the pressuriser and into auxiliary heating such as deaerators.

Temperature can be measured using standard J or K type thermocouples, some of them individually calibrated. The facility thermocouples will measure fluid, heater wall, piping wall and ambiant temperatures.

Pressures (absolute and differential) can be measured using capacitance / inductance diaphragm type or balanced bridge strain gage pressure transducers. The absolute pressures are measured in the PHTS in the headers and in the secondary and auxiliary systems.

Flows can be either measured or calculated from power and temperature data. For measurement of flow, single and bidirectional turbine meters, rotometers, strain probes, ultrasound meters can be used. In some instances flow indicators, rather than flow meters can be used.

Direct void measurements in high pressure and temperature metal pipes of the thermosyphoning facility can be expensive and specially under fast transients. For example gamma densitometry in the facility pipes would require long sampling times or very strong sources. Void can also be indicated using differential pressure transducers.

D. MEASURED QUANTITIES

This section describes what quantities need to be measured (and why) to describe the state of the system under steady state and controlled transient conditions to provide data for safe and controlled operation, experimental transients, feedback control and safety. Some quantities are measured directly, others are

inferred by later calculations. Major effort is devoted here to the instrumentation requirements of the PHTS.

1. Absolute Pressure

Why :
. To assess wether the facility is properly scaled.
. To determine fluid properties.
. To determine hydraulic loss coefficients.
. To assess pump performance.
. To determine driving forces.
. To provide safety trips.

Where :
. Pump suction (1x2)
. Pump discharge (1x2)
. Inlet header (1x2)
. Inlet end fittings (1x10)
. Outlet end fittings (1x10)
. S. G. plenum (1x2)
. S. G. outlet plenum (1x2)
. Pressuriser (2x1)

2. Fluid Temperature

Why :
. To determine fluid properties.
. To determine channel flow rates.
. To determine heat losses and heat balance.
. To determine whether steady state is achieved.
. To determine the state of the fluid at pump suction.

Where :
. Pump suction (1x2)
. Pump discharge (1x2)
. Inlet header (1x2)
. Channel inlet (1x10)
. Channel exit (1x10)
. Headers (2x2)
. Feeders (2x10)

3. Power

Why :
. Major independent variable.
. Heat balance.
. To determine channel flows.

Where :
. Fuel bundle (2x10)
. Pressuriser heaters (1)

4. Ambient Temperature

Why :
. To assess heat losses.
. To signal system leaks.

Where :
. To be determined later.

5. Flow

Why :
. To determine pump rundown.
. To determine major loss coefficient.
. Major dependent variable.
. To assess liquid holdup rates.
. To determine break discharge.

Where :
. Pump suction (1x2)
. Outlet header to steam generator (1x2)
. Break locations (4x1)
. Feeders (2x2)

6. Fuel Temperature

Why :
. Major dependent variable.
. To assess fuel cooling mode.
. To assess heat up rates.
. To provide heat balance.
. To provide trip signals.

Where :
. Top 2 pins of each channel (2x3x10)
. Pressuriser heaters.

7. Flow Statification

Why :
. Indicator of brakdown of flow in channel.
. Indicator of liquid holdup in steam generators.
. Indicator of onset of fuel pin heatup.
. Indicator of heatup of uninstrumented fuel pins.
. Indicator of countercurrent flow in feeders.

Where :
. Fuel channels (1x10)
. Headers (2x2)
. Feeders (1x5)

8. Liquid Holdup In Steam Generator Tubes

Why :
. Indicator of breakdown of carryover flows.
. Indicator of inventory distribution in the PHTS.

Where :
. One steam generator tube per pass.

9. Presence Of Non Condensibles

Why :
. Non condensibles raise the system pressure and delay carryover thermosyphoning flows.

Where :
. Temperature and sampling probe at the top of one steam generator.

10. Heat Losses

Why :
. To assess heat balance.
. To assess scaling implications.
. To assess effect on flow regime transitions.

Where :
. All components.
. Feeders.
. Headers.
. Channels.
. Piping.
. Steam generator shroud.
. Pressuriser.

E. MEASUREMENT LOCATIONS AND TRANSDUCERS

In the following, we identify the measurement location (component), the parameter to be measured and the type of instrumentation needed.

1. Channels

Power : Hall-effect watt transducers.
Fluid temperature : thermocouples.
Heater wall temperature : thermocouples.
Pressure tube wall temperature : thermocouples.
Cross channel pressure drop : differential pressure transducer.
Flow : calculated.
Heat loss : calculated.

2. End Fittings

Fluid temperature : thermocounles.
Heat loss : calculated.
Pressure : strain gage pressure transducer.

3. Inlet Header

Pressure : strain gage pressure transducer.
Fluid temperature : thermocouple.
Fluid level : differential pressure transducer.

4. Outlet Header

Pressure : strain gage pressure transducer.
Fluid temperature : thermocouple.
Fluid level : differential pressure transducer.

5. Pump

Suction pressure : pressure transducer.
Discharge pressure : pressure transducer.
Suction temperature : thermocouple.
Flow : orifice.

6. Piping

SG. inlet flow : orifice.
Break line flow : orifice.

7. Feeders

Flow : orifice
Wall temperature : thermocouple.

8. Pressuriser

Pressure : absolute pressure transducer.
Wall temperature : thermocouple.

9. Steam Generator Primary Side

Inlet plenum temperature : thermocouple.
Inlet plenum pressure : pressure transducer.
Outlet plenum temperature : thermocouple.
Outlet plenum pressure : pressure transducer.

10. Steam Generator Shroud

Wall temperature : thermocouple.

11. Insulation

Wall temperature : thermocouple.

F. QUANTITIES DISPLAYED IN REAL TIME

The following defined parameters will be displayed in real time during steady state and transient operation of the facility.

1. Pressure

Pump suction : 2
Inlet header : 2
Outlet header : 2
Pressuriser : 1

2. Fluid Temperature

Pump suction : 2
Inlet header : 2
Outlet header : 2
Channel inlet : 10
Channel outlet : 10

3. Power

Bundle : 10
Pumps : 2 (on/off)

4. Flow

Pump suction : 2
Channel : 10

G. IDENTIFICATION OF INSTRUMENTATION LOCATIONS

This section summarises the instrumentation locations. The recommandations contained herein reflect the minimum number of measurement points. Some of the measurement locations serve an additional function as inputs to safety and or control logic and are not specified as such.

1. Temperature

The instrumentation for temperature will cover wall temperature measurements inside and outside the PHTS, ambient air, liquid in the PHTS, secondary side and auxiliary systems and vapor/air.

1.1 Channel Temperature Measurements

Type	Location	Total Points
Sheath thermocouple	a. Top pin heated length entrance	10
	b. Top pin (1/4 length)	10
	c. Top pin (1/2 length)	10
	d. Top pin (3/4 length)	10
	e. Top pin heated length exit	10
	f. Centre pin (1/2 length)	10

	g. Bottom pin (1/2 length)	10
Wall temperature	h. Pressure tube	2
Sheath thermocouple	i. Inlet end fitting	10
	j. Outlet end fitting	10
	k. Heated length entrance	10
	l. Heated length middle	10
	m. Heated length exit	10

Measurement of axial wall temperature using embedded sheath thermocouples at 5 axial locations in the top pin of each channel will help not only identify heat transfer modes in the channel but also combined with the measurements of fluid temperatures and wall heat flux provide quantitative data on heat transfer coefficients. Channel flow rates can be determined from the measurements of fluid temperature rise across the channel and the power input. Measurement of wall temperature in three vertical locations in the middle of the channel will provide information on flow stratification and on different heat transfer modes in the subchannel.

In some thermosyphoning scenario, it could be expected that the entire channel is filled with steam. Identification of such scenario and the subsequent fuel heatup rates and steam temperature data can be obtained through the specified instrumentation.

1.2 PHTS Fluid Temperature Measurements

Location	Number of points in the rig
a. Feeder inlet	10
b. Feeder outlet	10
c. Inlet header	2
d. Outlet header	2
e. SG inlet lines	4
f. Pump suction	2
g. Pump discharge	2
h. SG. inlet plenum	2
i. SG. outlet plenum	2
j. Pressuriser	2

Points a. and b. along with pressure measurements, will give information on the driving force that is available to drive a flow trough a channel and to help determining the direction of that flow.

Points c. and d. will give an assessment of the flow mixture and enthalpy distribution in the headers along with a. and b., and in case of flow bypass of the steam generator will help in determining the flow pattren in the core.

Points e. f. and g. will give information on the eventual bypass of the steam generator, and by coupling these measurements with a flow measurement will permit to calculate the heat load to the steam generator and verify the secondary side heat balance.

Figures 4, 5 and 6 show the location of the temperature measurement points in the PHTS.

1.3 Auxiliary Temperature Measurements

Location	Number of points in the rig
SG secondary side cold leg	4
SG secondary side hot leg	4
SG secondary side top of tube bundle	4
SG secondary side feedwater inlet	4
SG secondary side steam outlet	4
Main condenser inlet	1
Main condenser outlet	1
Service water inlet	1
Service water outlet	1
Deaerator tank	1
Service water source tank	1
Service water sink tank	1
Surge tank	1
ECCS tank	1
Break heat exchanger	4
SDCS heat exchanger	4
Bleed heat exchanger	4
PHTS piping wall	10
Ambiant	3

All of the above measurements will be used to calculate the heat balances, evaluate the heat losses and control the facility.

2. Pressure

Experience shows that during single phase thermosyphoning the pressure of the system is very stable and controlled by the heat exchange or cooldown rate of the steam generators. In case of two phase thermosyphoning with intermittent flows in the channels the system pressures vary extremely rapidly throughout the PHTS. Such pressure information is very difficult if not impossible to analyse unless auto correlation methods are employed in analysing the data. Consistant with the aim of the facility, the proposed pressure instrumentation of the rig is going to be designed for the points given below.

2.1 PHTS Pressure Measurements

Location	Number of points in the rig
a. Across channel (dp)	10
b. OH - IH (dp)	2
c. OH - channel (dp)	10
d. IH - channel (dp)	10
e. OH (absolute)	2
f. IH (absolute)	2
g. Middle of channel (absolute)	10
h. Pump suction (absolute)	2

Points a., b., c. and d. will give the driving force for the flow across a channel and should give the flow direction. Points e., f., g. and h. will permit the calculation of the amount of subcooling in various parts of the system.

Figures 7 and 8 show the location of the PHTS pressure measurement points.

2.2 Auxiliary Pressure Measurements

Location	Number of points in the rig
a. Steam generator secondary side	2
b. ECI accumulator	1
c. Pressuriser	1
d. Surge tanks	2
e. Feedwater inlet	2
f. Auxiliary pumps	3
g. Main condenser inlet and outlet	2

All these measurements are mostly facility control points but will be used in the analysis of the results.

Figure 9 shows the location of the measurement points.

3. Flows

The magnitude of the different flows through the system is the most valuable information for understanding the thermosyphoning phenomena. Under single phase condition, using calibrated temperature instrumentation, the flow can be determined easily when the heat balance is known. Temperature instrumentation throughout the system will also be an indicator of flow direction. When the system is near saturation temperature the temperature information is useless for flow calculation. Unfortunately at the same time single phase flow measurement devices either go out of range or start to be unreliable.

The flow measurement that is really of interest is the flow through the channel which cannot be directly measured and has to be estimated by measuring the feeder flow. Instrumentation for flow measurement through the feeders would have to be able to function in forward and reverse direction since reverse flows are expected to occur. The history of the temperature profiles in a channel that can be drawn from the temperature measurements should enable to deduct the flow direction at any point in time.

During thermosyphoning, the driving forces generated by the gravity head, through the system are very small and any intrusive instrumentation such as orifices for flow measurements could distort or change the phenomena of interest.

For all these reasons we do not recommend flow measurements in the feeders.

3.1 PHTS Flow Measurements

All flow instrumentation is specified for single phase measurement only, unless otherwise stated.

Location	Number of points in the rig
a. Steam generator inlet lines	4
b. Pump suction line	2

Measurement points a. and b. will enable to have a semi direct reading of the gross flow trough the system. Combined with the other flow determination, this will permit to calculate the extend of steam generator bypass.

3.2 Auxiliary Flow Measurements

Location	Number of points in the rig
a. Feed water line	2
b. ECI lines	4
c. Break discharge	4
d. SDCS lines	4

The above flow measurement points will be used mainly for loop control but also for heat balance purpose and system behaviour assessment.

4. Power

The rig is going to be electrically heated with variable power capability to each individual channel.

Location	Number of points in the rig
a. Channels	10
b. Top pins	10
c. Pump motor	2
d. Pressuriser	1

Measurement point a. gives the power to each channel for flow calculation purposes, heat balance and control.

In case of channel stratification the uncovered pins may have a change in electrical resistance and a change in heat generation that can be monitored by instrumentation point b.

Point c. will be used to monitor the pump rundown.

5. Void

It is expected that the most valuable information will be gathered during two phase phenomena. In that case the determination of the local flow regime could be achieved through void fraction measurement techniques. If a technique exists and is compatible with the time transients of the two phase thermosyphoning phenomena void measurements should be done at the following locations.

Location	Number of points in the rig
a. Top of feeders	20
b. channel inlets	10
c. Channel outlets	10
d. Steam generator inlet lines	4
e. Pump suction	2

Void measurement techniques are usually non intrusive and we have listed above the maximum locations for instrumentation, which are independent of the actual number of instruments needed.

Points a., b. and c. will give a clear indication on whether two phase flow occur in the channels and the extend and duration of voiding. Points d. and e. will show if reflux condensation is a mode of cooling the rig.

H. INSTRUMENTATION SUMMARY

Table 1 gives a summary of the instrumentation locations for temperature, along with periods of scanning. Table 2 gives a summary of the instrumentation locations for pressure, flow, power and void, along with periods of scanning.

Excluding the void measurements the total number of instrumentation points is around 400. The minimum measurement period is 0.1 second and the longest 20 seconds. Those periods are defined for transients only and during steady state operation the scanning frequency can be reduced.

Based on those numbers the data acquisition system must be able to handle about 1200 data per second or more.

I. CONTROL

The control of the facility has two goals. The first one must estasblish the overall safety of the rig and enable it to achieve the desired steady state conditions which will be the reference point for a particular transient. The second one aims at duplicating the response of a Candu plant in case of loss of class IV power, followed or preceeded by an accident.

The measurements to be monitored are given below and are divided into operation, safety and experiments.

1. Operation

Location	number of points in the rig
Power.	
a. Channel	10
b. Pressuriser	1
c. Pumps	2
Flow.	
a. Pump suction	2
b. Auxiliary pumps	6
c. Feedwater	2
Pressure.	
a. Outlet header	2
b. Pressuriser	1
c. S. G. secondary side	2
d. Auxiliary systems	5
Temperature.	
a. Top pin	10
b. Pressuriser	2
Water level.	
a. S. G. secondary side	2
b. Pressuriser	2

2. Safety

The facility will not have a duplicated and independent safety system. The facility's trip setpoints will use the control points measurements for protection against high temperature and overpressure.

It is intended to monitor all channel temperatures for trip parameter. Depending on the actual number of spurious trips during steady state operation the number of monitored channels could be reduced.

The thermosyphoning experiments should be run at pressures lower than the operating or design pressure of the rig. Nevertheless the overpressurisation trip parameters will be doubled and each outlet header will have two pressure measurements.

3. Experiments

During experiments, the previous safety protection will remain in place, but the trip setpoints of high temperature will be raised. All primary side flow controls will be inhibited along with steam generator and pressuriser level which will be reprogrammed according to their behaviour in a Candu 600 following a loss of class IV power.

The channel power will be programmed to simulate the core decay heat. The pumps will be rundown to create the desired enthalpy distribution in the system.

J. DATA ACQUISITION

The data acquisition system is designed with a fast scanning and data management capability. It will have a data management and control function and consist of the hardware and software described below.

1. Data Management

The design guidelines for the data management are as follows :

1. Acquire raw analog data at specified scanning rates.
2. Convert the raw data into digital data.
3. Store digitised data at specified time intervals.
4. Convert some of the data into engineering units at specified intervals.
5. Display selected data on CRTs.
6. Plot engineering and raw data for specified data channels.
7. Store raw and engineering data on magnetic tape and hard disks.
8. Print specified data on line printer.
9. Display some of the instrumentation ports directly.
10. Use real time and stored data for on line analysis, using loop specific software.

2. Control

The design basis for the control data are as follows :

1. Obtain control parameters from the raw data with computer interface and directly from the instrumentation ports.
2. Obtain data on state of the systems and components.

3. Compare control parameters to the data on the state of the system through electromechanical comparators or computer software.
4. Deliver contact closure or opening signals to implement control dicisions.
5. Interface with operator control panel for automatic and manual safaty overrides of control signals.
6. Interface with operator consol board.

3. Components

Consistent with the design guidelines, the data acquisition system has been chosen to contain the followiny major components:

1. Computer.
2. Scanner - A/D converter.
3. D/A converter.
4. Contact closure panel.
5. A/D converter for operator control panel.
6. CRT displays.
7. Multipen analog plotters
8. Tektronix/VT-52 CRT display for real time plots.
9. Mag disk for data storage and retrieval.
10. Mag tape for data storage.
11. Line printer.
12. Digital plotters.

4. Software

Most of the software necessary to operate the loop would have to be written prior to experimentation. We list below the different software packages that are necessary:

1. Calibration files for data conversion into engineering units.
2. Software for loop control.
3. Software for test matrix.
4. Software for scanning, storage and plotting.
5. Thermohydraulic simulation code.

Table 1

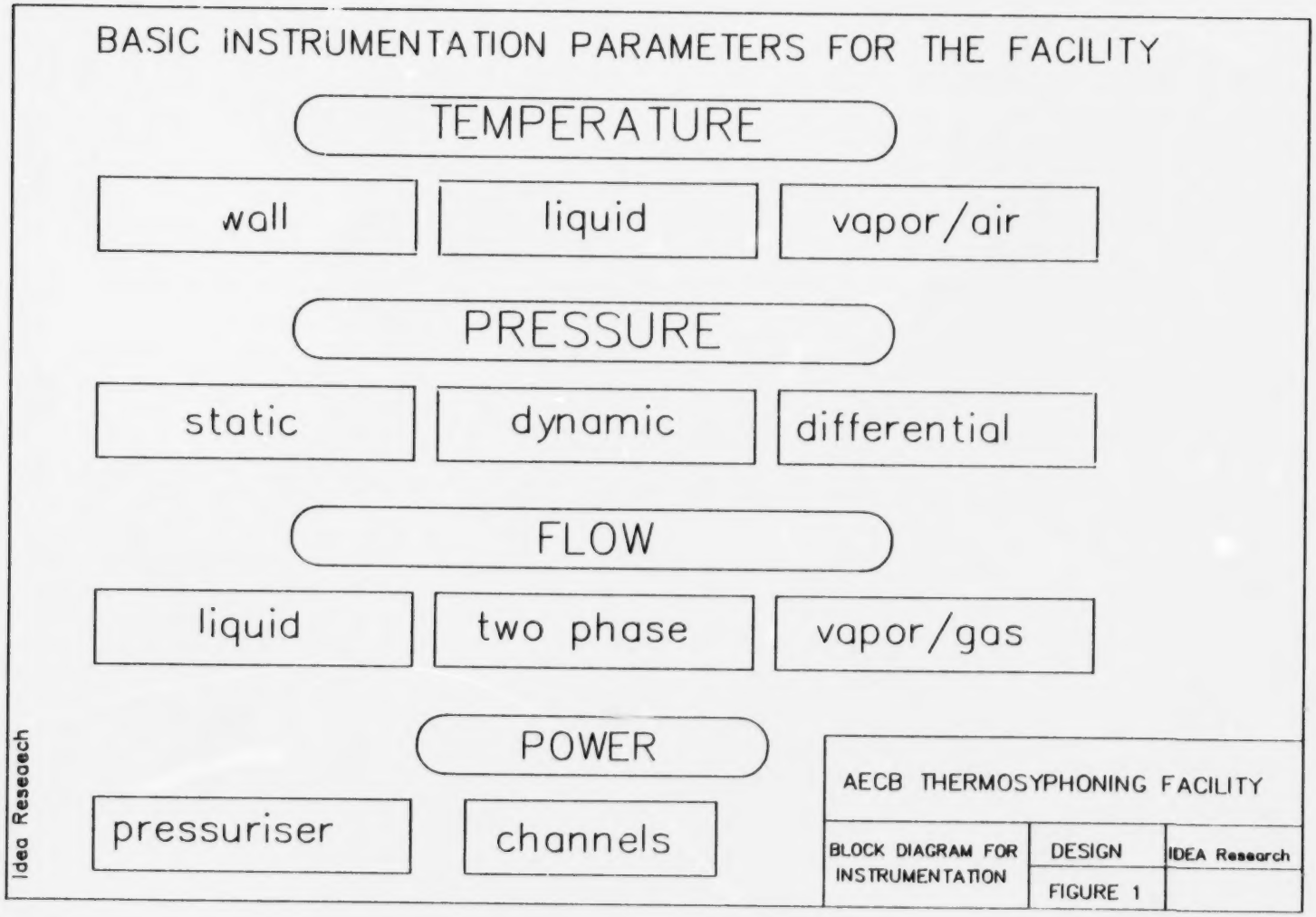
Temperature locations and data acquisition period summary

Location	Number of points in the rig	Measurement period(s)
Top pin entrance	10	0.1 to 1.0
Top pin (1/4 length)	10	0.1 to 1.0
Top pin middle	10	0.1 to 1.0
Top pin (3/4 length)	10	0.1 to 1.0
Top pin exit	10	0.1 to 1.0
Centre pin middle	10	0.1 to 1.0
Bottom pin middle	10	0.1 to 1.0
Heated section inlet (fluid)	10	1
Heated section middle (fluid)	10	1
Heated section outlet (fluid)	10	1
Channel inlet (fluid)	10	0.1 to 1.0
Channel outlet (fluid)	10	0.1 to 1.0
Pressure tube outer wall	2	1
Feeder inlet (near EF)	20	1
Feeder outlet (near header)	20	1
Inlet header	4	1
Outlet header	4	1
SG inlet lines	4	1
Pump suction	2	1
Pump discharge	2	1
SG inlet plenum	2	1
SG outlet plenum	2	1
Pressuriser	2	1
S.G. secondary side	10	1.0 to 5.0
Main condenser	4	1.0 to 5.0
Deaerator tank	1	1.0 to 5.0
Service water source	4	1.0 to 5.0
Service water sink	4	1.0 to 5.0
Surge tank	4	20
Pressuriser heater wall	4	1
ECI tank	1	20
SDCS heat exchanger	4	0.1 to 5.0
Bleed heat exchanger	4	0.1 to 5.0
PHTS piping wall	10	5
Ambiant	3	20
Total points	225	

Table 2

Pressure, flows, power and void locations
and data acquisition period summary

Location	Number of points in the rig	Measurement period(s)
Pressure.		
Across channel (dp)	10	0.1
OH - IH (dp)	2	0.1
OH - channel (dp)	10	0.1
IH - channel (dp)	10	0.1
OH (absolute)	2	1.0
IH (absolute)	2	1.0
Middle of channel (absolute)	10	1.0
Pump suction (absolute)	2	1.0
S. G. secondary side	2	1.0
ECI accumulator	1	10
Pressuriser	1	1.0
Feddwater	2	5
Auxiliary pumps	3	5
Condenser	2	5
Surge tanks	2	5
Total	61	
Flow.		
Steam generator inlet lines	4	1.0
Pump suction line	2	0.1
Feed water line	2	1.0
ECI lines	4	1.0
Break discharge	4	0.1
SDCS lines	4	1.0
Total	20	
Power.		
Channels	10	1.0
Top pins	10	1.0
Pump motor	2	1.0
Pressuriser	3	10
Total	25	
Void.		
Top of feeders	20	
channel inlets	10	
Channel outlets	10	
S.G. inlet lines	4	
Pump suction	2	
Total	46	


BASIC INSTRUMENTATION PARAMETERS FOR THE FACILITY
TEMPERATURE
wall
liquid
vapor/air
PRESSURE
static
dynamic
differential
FLOW
liquid
two phase
vapor/gas
POWER
pressuriser
channels
Idea Research
AECB THERMOSYPHONING FACILITY
BLOCK DIAGRAM FOR INSTRUMENTATION
DESIGN
IDEA Research
FIGURE 1

TEMPERATURE MEASUREMENT

FLUID

- INLET HEADER *
- FEEDER ORIFICE
- INLET END FITTING
- HEATER INLET
- MID CHANNEL *
- HEATER OUTLET
- OUTLET END FITTING
- MID OUTLET FEEDER
- OUTLET HEADER *
- S.G INLET PLENUM
- S.G OUTLET PLENUM
- PUMP INLET
- PUMP OUTLET
- PRESSURISER *

VAPOR / AIR

- AMBIENT *
- INLET HEADER
- CHANNEL
- OUTLET HEADER
- PRESSURISER

FUEL

- TOP PINS *
- BOTTOM PIN
- PRESSURISER

PIPING

- HEADERS
- PRESSURE TUBE *
- FEEDERS *
- PROCESS PIPING

instrumentation

Calibrated thermocouples

* multiple

Idea Research

AECB THERMOSYPHONING FACILITY		
TEMPERATURE MEASUREMENT	DESIGN	IDEA Research
	FIGURE 2	

PRESSURE MEASUREMENT

ABSOLUTE

INLET HEADER
OUTLET HEADER
S.G. INLET PLENUM
TOP S.G TUBE
PUMP SUCTION
PUMP DISCHARGE

PRESSURISER •

SECONDARY SIDE •

S.D.C.S •

OTHER SECONDARY SIDES •

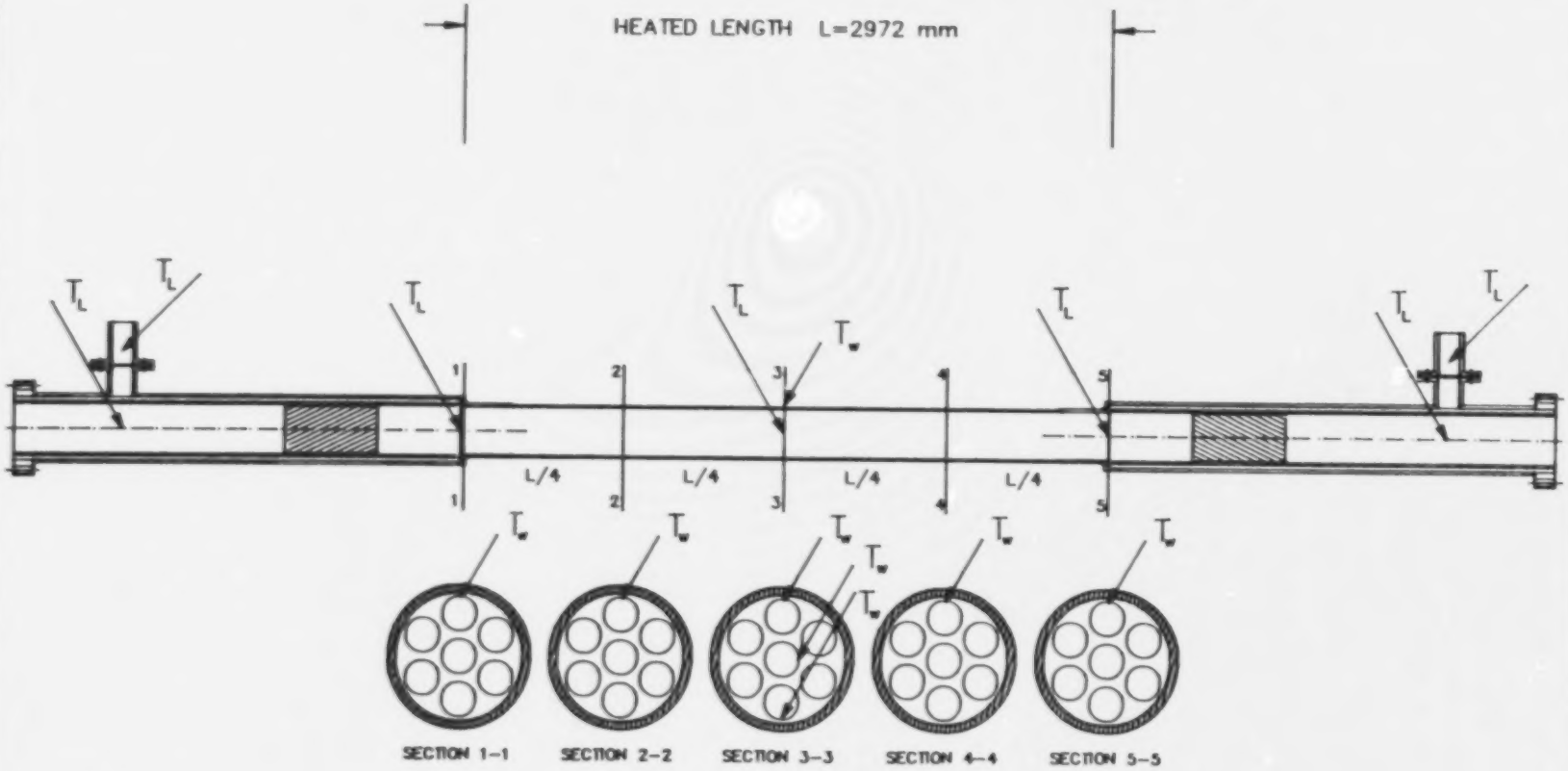
DIFFERENTIAL

HEADER TO HEADER
ACROSS CHANNEL
INLET HEADER – INLET E.F
OUTLET HEADER – OUTLET E.F
INTRAPASS HEADER– HEADER
PRESSURISER •
SECONDARY SIDE •
S.D.C.S •

• locations upon design

Idea Research

AECB THERMOSYPHONING FACILITY		
PRESSURE	DESIGN	IDEA Research
	FIGURE 3	

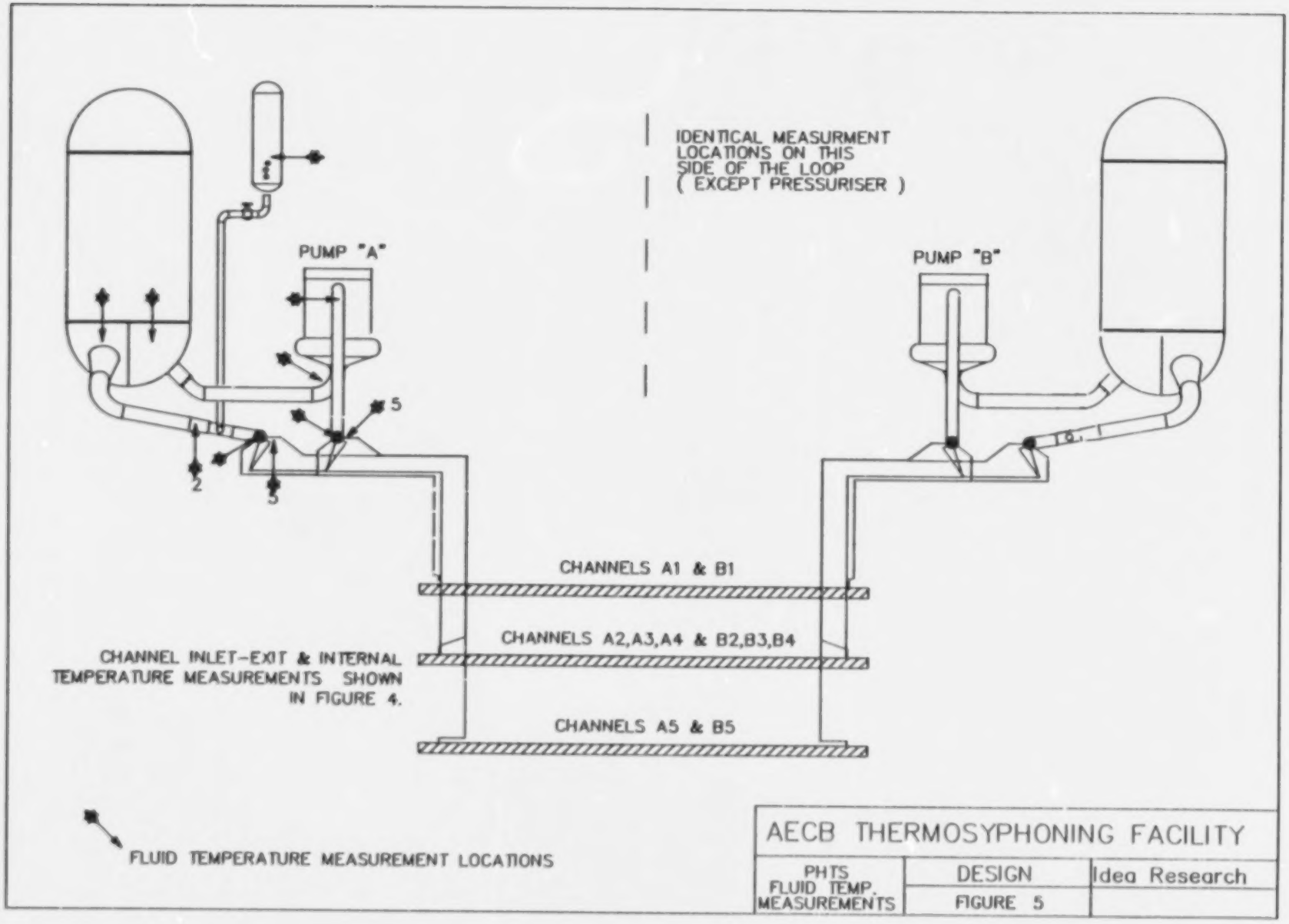


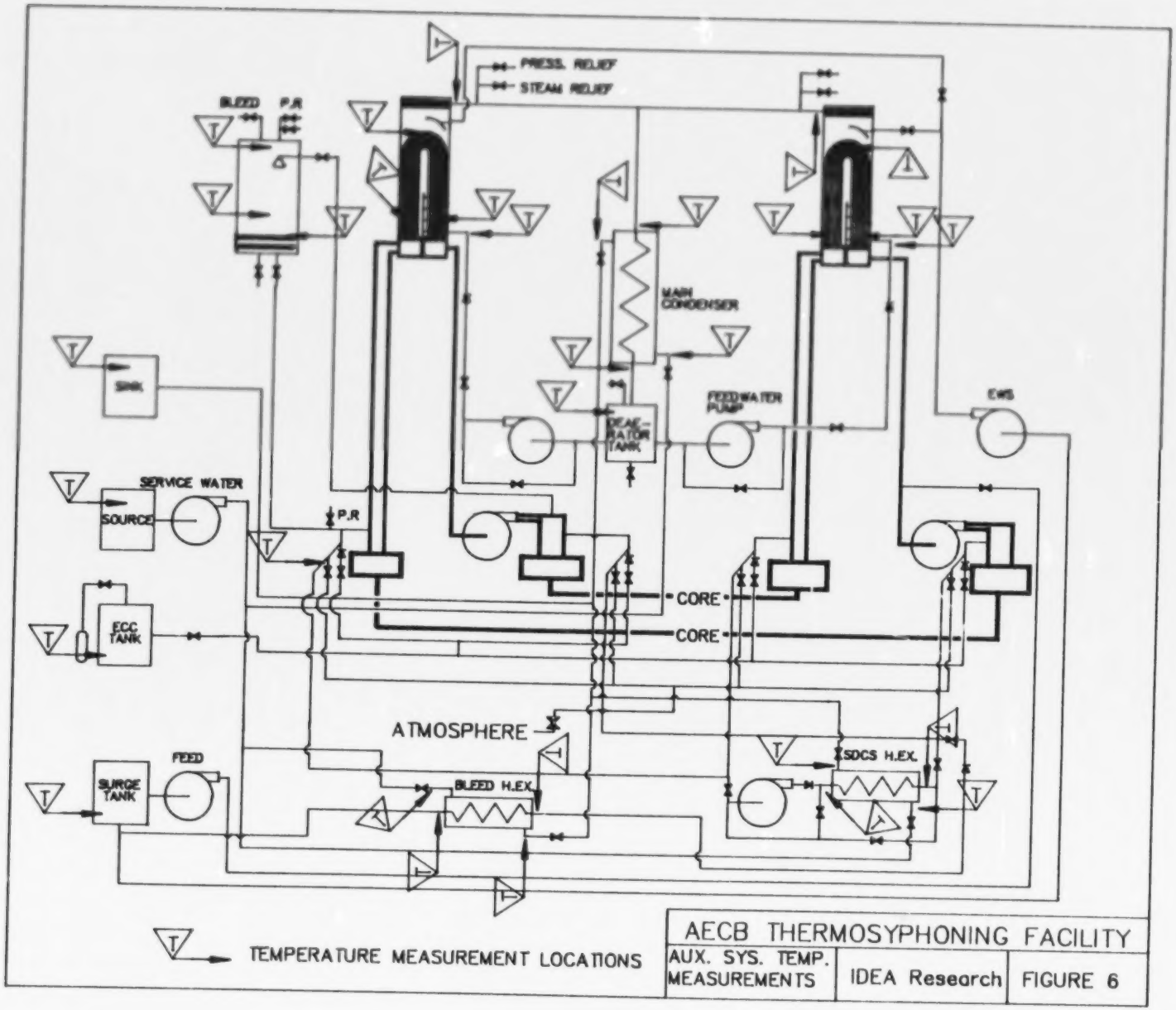
FUEL SHEATH THERMOCOUPLE LOCATIONS

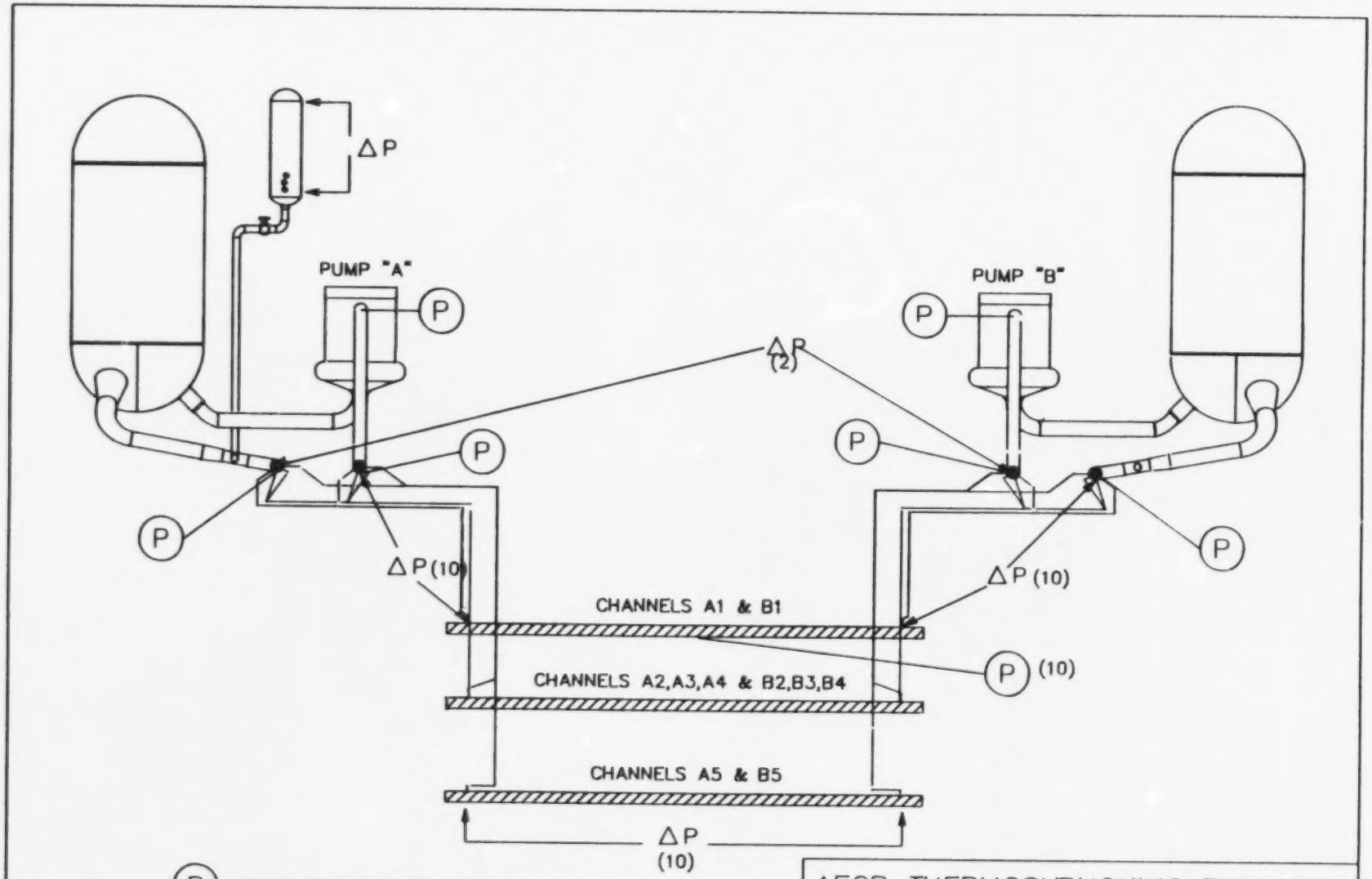
T_w – WALL THERMOCOUPLE

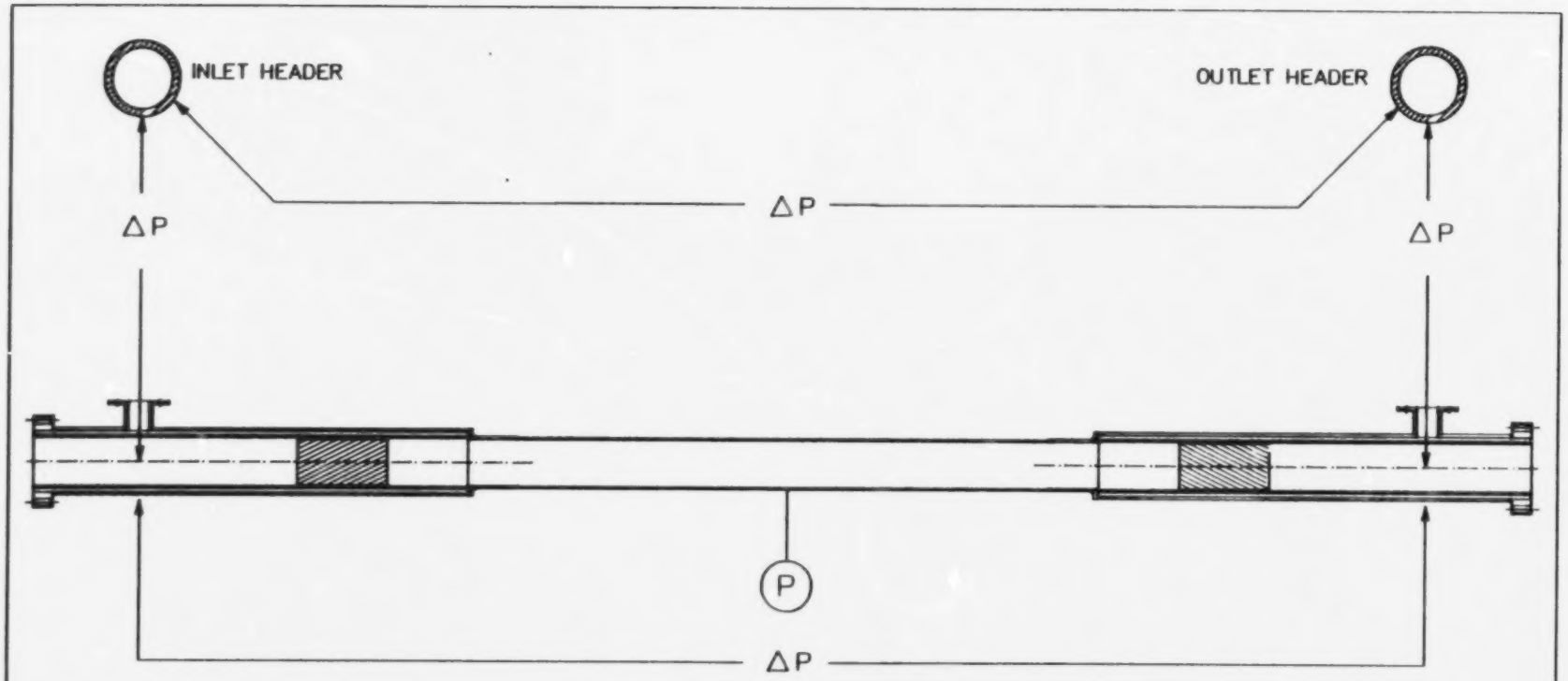
T_L –FLUID THERMOCOUPLE

AECB THERMOSYPHONING FACILITY		
CHANNEL INSTRUMENTATION	DESIGN	IDEA Research
	FIGURE 4	


IDENTICAL MEASURMENT
LOCATIONS ON THIS
SIDE OF THE LOOP
(EXCEPT PRESSURISER)
PUMP "A"
PUMP "B"
5
2
3
CHANNELS A1 & B1
CHANNELS A2,A3,A4 & B2,B3,B4
CHANNELS A5 & B5
CHANNEL INLET-EXIT & INTERNAL
TEMPERATURE MEASUREMENTS SHOWN
IN FIGURE 4.
FLUID TEMPERATURE MEASUREMENT LOCATIONS
AECB THERMOSYPHONING FACILITY
PHTS
FLUID TEMP.
MEASUREMENTS
DESIGN
Idea Research
FIGURE 5


PRESS. RELIEF
STEAM RELIEF
BLEED P.R
MAIN CONDENSER
SINK
FEEDWATER PUMP
DEAE-RATOR TANK
EMS
SERVICE WATER
SOURCE
P.R
CORE
CORE
ECC TANK
ATMOSPHERE
SDCS H.EX.
FEED
SURGE TANK
BLEED H.EX.
TEMPERATURE MEASUREMENT LOCATIONS
AECB THERMOSYPHONING FACILITY
AUX. SYS. TEMP. MEASUREMENTS
IDEA Research
FIGURE 6

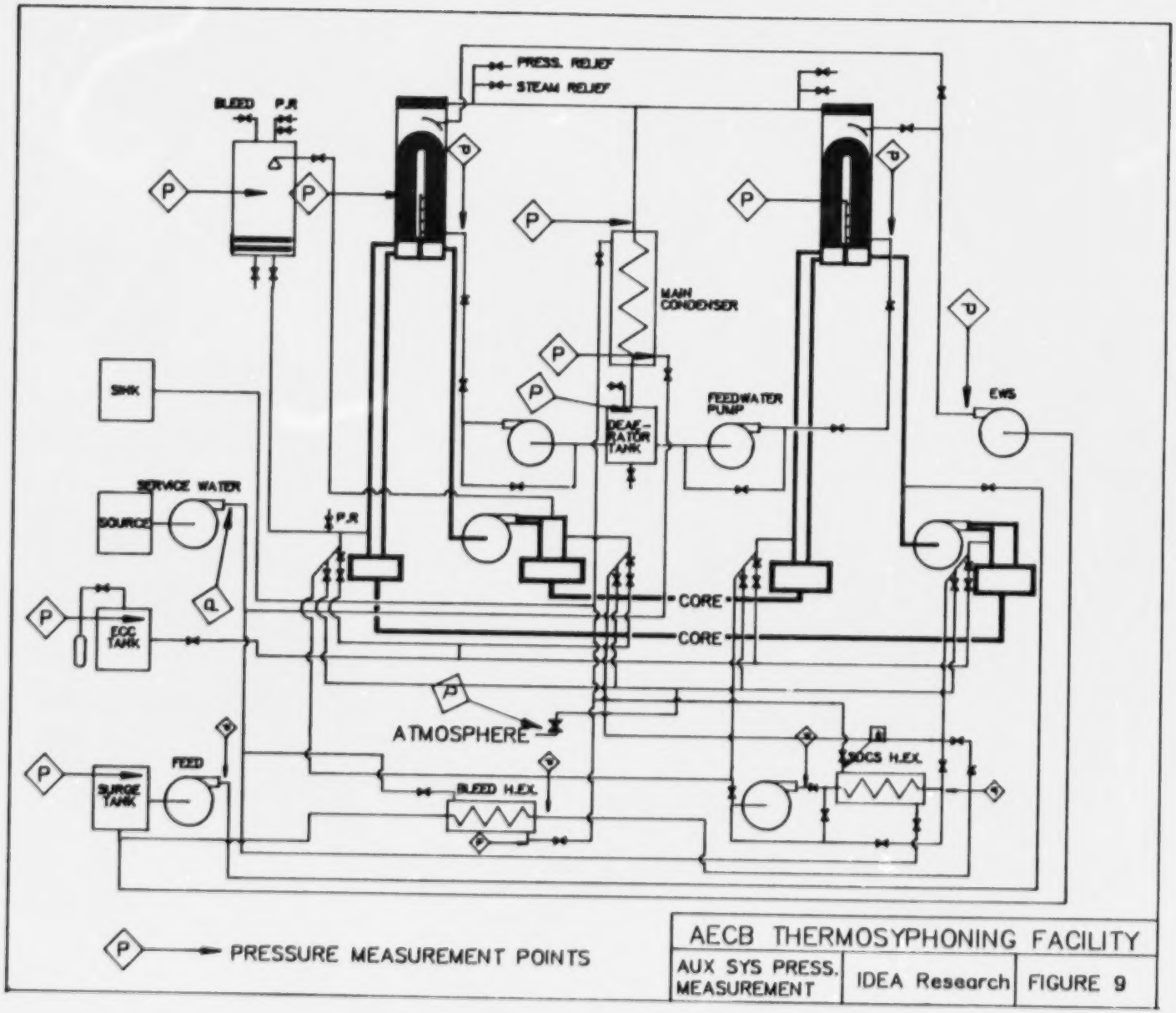

ΔP
PUMP "A"
PUMP "B"
P
ΔP (2)
ΔP (10)
CHANNELS A1 & B1
CHANNELS A2,A3,A4 & B2,B3,B4
CHANNELS A5 & B5
ΔP (10)
P (10)
ΔP (10)
P ABSOLUTE PRESSURE MEASUREMENT LOCATION
ΔP DIFFERENTIAL PRESSURE MEASUREMENT LOCATIONS
AECB THERMOSYPHONING FACILITY
PHTS PRESSURE MEASUREMENTS
DESIGN
Idea Research
FIGURE 7



P ABSOLUTE PRESSURE MEASUREMENT

ΔP DIFFERENTIAL PRESSURE MEASUREMENT

AECB THERMOSYPHONING FACILITY		
CHANNEL PRESSURE MEASUREMENTS	DESIGN	Idea Research
	FIGURE 8	


PRESS. RELIEF
STEAM RELIEF
BLEED
P.R
MAIN CONDENSER
SINK
FEEDWATER PUMP
DEAE-RATOR TANK
EWS
SERVICE WATER
SOURCE
P.R
CORE
CORE
ECC TANK
ATMOSPHERE
FEED
SURGE TANK
BLEED H.EX.
SDCS H.EX.
PRESSURE MEASUREMENT POINTS
AECB THERMOSYPHONING FACILITY
AUX SYS PRESS. MEASUREMENT
IDEA Research
FIGURE 9

SECTION 5

- SPECIFICATIONS -

A. INTRODUCTION

This section outlines the major dimensions and operational and design requirements of major components of the facility. These specifications can be used to generate detailed drawings of components that can be used for manufacture and assembly. Thus these data and drawings are not intended to be detailed and reflect only the information generated in the conceptual design stage. Major dimensions and operational conditions are specified. Only the internal flow dimensions are specified and the overall outer dimensions for PHTS elements like pipes, headers, channels will be specified during the detailed design stage. Where appropriate figures are included to illustrate the component shape and characteristics.

More attention is paid to the specifications of the primary heat transport system. The auxiliary systems are presented as boundary conditions leaving some flexibility for the final design and procurement stage. The instrumentation for the thermosyphoning facility and its auxiliary systems is described in Section 2 and only a final list of required instrumentation is included.

B. COMPONENTS SPECIFICATIONS

1. Primary Heat Transport System

1.1 Inlet Headers

Figure 1 shows an axial sketch of the inlet header. Figure 2 shows a cross sectional view.

1.1.1 Geometric Data

Total internal length	2002	mm
internal diameter	101.9	mm
Length between inlet lines	800.8	mm
Number of flanges (ports)	9	
Unused flange plates	4	

1.1.2 Quantity

Two identical inlet headers are required.

1.1.3 Thermohydraulic Data

Operating pressure range	0.1 to 11.23	MPa
Operating temperature range	20 to 280	°C

1.1.4 Material

ASTM A106 Grade B steel or equivalent.

1.2 Outlet Headers

Figure 3 shows an axial sketch of the outlet header. Figure 4 shows a cross sectional view.

1.2.1 Geometric Data

Total internal length	2018	mm
Internal diameter	111.8	mm
Length between outlet lines	807.2	mm
Number of flanges (ports)	9	
Unused flange plates	4	

1.2.2 Quantity

Two identical outlet headers are required.

1.2.3 Thermohydraulic Data

Operating pressure range	0.1 to 11.23	MPa
Operating temperature range	20 to 280	°C

1.2.4 Material

ASTM A106 Grade B steel or equivalent.

1.3 Feeders

Of the five channels in each pass of the figure of eight thermosyphoning facility, two channels are positioned identical to each other. The feeders for channels A-2 and A-4 are identical geometrically and differ only in layout. Figures 5 through 20 show the geometric characteristics of the feeders. The geometric data for the various feeders is given in appendix S5-1. The data are presented in scaled lengths of the actual feeder of the Candu 600. The sections are numbered beginning at the channel so that the section number 1 corresponds to the pipe section immediately attached to the endfitting. The coordinate system is chosen as follows :

z : along the channel axis
y : vertically up from the endfitting
x : perpendicular to the channel axis.

There is a unique set of axes for each channel. The origin in each case lies at the channel center line at the feeder connection. The last feeder section ends at the header and its length is specified to the center line of the header. This would allow adjustments to the feeder connection flanges and fittings at the channel and header ends, with corresponding trimming of the last feeder section length.

The feeders have the surface finish of drawn tubing.

1.3.1 Geometric Data

See Appendix S3-1.

1.3.2 Quantity

Inlet feeders :	10
Outlet feeders :	10
Inlet feeders type :	4
Outlet feeders type :	4

1.3.3 Thermohydraulic Data

Design pressure range	0.1 to 11.3	MPa
Design temperature	20 to 310	°C

1.3.4 Material

ASTM A106 Grade B steel or equivalent.

1.4 Channels

A channel consists of full length electrically heated 7 pin bundles in a pressure tube and integral inlet and outlet and fittings. Figure 25 shows a schematic of a fuel bundle cross section. Figure 26 shows a schematic of the electrical element of a fuel bundle. Figure 27 shows the fuel channel assembly. The end fitting details are given in Figure 28. The inlet and outlet end fittings are identical and constitute along with the pressure tube, the channel. The end fitting body is welded to the pressure tube. The liner tube slips over the fuel bundle and may be inserted in along with the flange. The liner tube has 8 holes per section in equally spaced (every 30mm) sections). Each end fitting has a shield plug that diverts the channel flow into the annulus around the liner tube. The shield plug must be restrained in it's desired axial location. Figure 29 gives a description of a shield plug.

1.4.1 Geometric Data

The following describes the geometric data of the pressure tube and end fittings assembly.

-Bundle		
Arrangement	6 around 1	
Pitch diameter of outer elements	29.76	mm
Number of spacers	11	
-Pin		
O.D	13.12	mm
Total length	5534	mm
Heated length	2972	mm
-Pressure tube		
I.D	45.29	mm
Length	2974	mm

-End fitting		
Length (excluding flange)	1180	mm
I.D	66.6	mm
Liner tube I.D	45.5	mm
Liner tube O.D	55	mm
Liner tube hole diameter	8	mm
Number of holes per section	8	
Axial spacing of holes	30	mm
Shield plug length	279	mm
I.D of shield plug holes	13.25	mm
Number of holes	7	
Radius of outer 6 holes circle	14.88	mm

1.4.2 Quantity

Bundles	10
Pins	70
Pressure tubes	10
End fittings	20

1.4.3 Thermohydraulic Data

Maximum pressure	11.5	MPa
Maximum pin temperature	800	°C
Maximum pressure tube temperature	500	°C
Maximum end fitting temperature	500	°C

1.4.4 Material

Pin	Zircaloy
Pressure tube	SS-304
End fitting assembly	SS-304

1.5 Steam Generators

Figure 30 shows a schematic of the steam generator. Figure 31 shows the proposed tube layout. Figure 32 shows a cross section of the steam generator in the tube sheet region. The overall height of the steam generator is not specified as it will be determined by the size and shape of the steam separation equipment.

Number of steam relief valves 4
Number of crash cool valves 2
Number of isolation valves 2

1.5.1 Geometric Data

Number of tubes	28	
Layout	triangular	
Tube pitch	23.81	mm
Tube I.D	13.62	mm
Tube I.D	15.875	mm
Wall thickness	1.13	mm

Surface area per metre	.05	m^2
Average tube length	9380	mm
Average tube height	4675	mm
height of preheater section	1335	mm
Number of baffles	4	
Tube sheet thickness	50	mm
Total heat exchange area	13.1	m^2
Outer limit of tube	230	mm
Downcomer shroud I.D	250	mm
Downcomer shroud O.D	260	mm
Shell I.D	325	mm
Shell O.D	360	mm
Number of primary inlet connections	2	
Inlet pipe I.D	48.4	mm
Number of primary outlet connections	1	
Outlet pipe I.D	47.1	mm

1.5.2 Quantity

Steam generators	2

1.5.3 Thermohydraulic Data

-Tube side		
Inlet pressure	9.89	MPa
Outlet pressure	9.61	MPa
Inlet temperature	309	°C
Outlet temperature	266	°C
Maximum heat load	500	kW
-Shell side		
Inlet temperature	180	°C
Feed water flow rate	.3	dm^3/s
Pressure	4.7	MPa
Exit quality	99.5	%

1.5.4 Material

U tubes	SS-304
Steam generator	Carbon Steel
Tube sheet	SS-304

1.6 Pumps

The pumps must be driven by variable speed electrical motors capable of controlled rundown and operation at low speeds.

1.6.1 Geometric Data

Internal diameter of pump suction line	47.1	mm
Internal diameter of discharge pipes	38.0	mm

1.6.2 Quantity

Number of pumps	2

1.6.3 Thermohydraulic Data

Suction pressure	9.5	MPa
Discharge pressure	11.24	MPa
Inlet temperature	266	°C
Resistance at zero speed (k value)	17.7	

1.7 Pressuriser

One pressuriser is used in the facility. Figure 33 shows a schematic of the pressuriser vessel. The heater port is located 200 mm from the bottom of the vessel and the spray port is located 100 mm from the top.

Number of steam relief valves	2 parallel
Number of PHTS,isolation valves	1
Number of spray isolation valves	1

1.7.1 Geometric Data

Vessel I.D	252	mm
Height	5	m
Length of heaters	150	mm
Number of heaters	2	

1.7.2 Thermohydraulic Data

Pressure	10	MPa
Temperature	310	°C

1.7.4 Material

ASTM 106 or equivalent

1.8 Major Piping

The following is a description of the primary system connecting pipes.

1.8.1 Geometric Data

-Outlet header to steam generator		
Length section1	600	mm
I.D	42.8	mm
Number of bends	0	
Length section2	1650	mm
I.D	48.4	mm
Number of bends	1	80 degrees
-Pump suction		
Length	2250	mm
I.D	47.1	mm
Number of bends	2	

-Pump discharge		
Length	1550	mm
I.D	38.0	mm
Number of bends	2	
-Interconnect		
Length	9350	mm
I.D	12.5	mm
Number of bends	6	
-Pressuriser surge line		
Length	7750	mm
I.D	19.1	mm
Number of bends	5	

1.8.2 Thermohydraulic Data

Pressure	11.5	Mpa
Maximum temperature	320	°C

1.8.3 Material

Carbon steel

2. Auxiliary Systems

The auxiliary systems are specified as support systems that must impose a set of boundary conditions on the primary heat transport system. The actual final design of these systems is site specific and has no bearing on the performance of the primary side of the facility. Figure 35 shows a schematic of the auxiliary systems. They include all systems outside of the PHTS pressure boundary including the various isolation valves.

2.1 Main Condenser and Feedwater System

Inlet steam quality	99.5	%
Maximum heat load	1.0	MW
Exit fluid temperature	187	°C
Feed water flow rate	.57	dm^3/s
Number of feed pumps	2	
Number of isolation valves (power op.)	2	
Number of throttle valves (power op.)	2	
Service water flow	10	dm^3/s
Service water inlet temperature	20	°C
Service water outlet temperature	40	°C

2.2 Emergency Water Supply

Flow per steam generator	.22	dm^3/s
Inlet temperature	20	°C
Number of isolation valves (manual)	2	
Pump head	30	m

2.3 Shutdown Cooling System

Maximum heat load	250	kW
Maximum primary flow	.66	dm^3/s
Maximum inlet temperature	200	°C
Maximum tube side pressure	5.	MPa
Service water flow	3.	dm^3/s
Service water inlet temperature	20	°C
Service water outlet temperature	40	°C

2.4 Emergency Core Cooling System

The emergency core cooling system can be designed with two option. The first one would comprise only the high pressure ECI part of the Candu 600 with an accumulator capacity designed to accommodate a small break flow for about one hour. The second option, more expensive and not really required for a small break study would set up the system as in a Candu 600 with three stages of ECI injection. The "break pipes" are connected to the pump discharge or steam generator inlet lines.

-"Break"

Number of inlet header "break pipes"	1
Number of outlet header "break pipes"	1
Discharge	to atmosphere
Number of quick acting relief valves	2
Number of isolation valves	2

-ECI lines

Length	Final design	
I.D	25	mm
Isolation Valves	5	
Check valves	2	

Option 1

- Accumulator

Volume	1600	dm^3
Pressure	4.0	MPa
pressure when empty	1.3	MPa
Water temperature	20	°C
Helium gas bottle pressure	20	MPa
Number of helium bottles	5	
Number of pressure regulators	5	
Number of gas valves	2	
Number of isolation valves (Power op.)	1	
Number of check valves	2	

-Pump

Pump shutoff head	1.3	MPa
Maximum flow	10	dm^3/s
Suction water temperature	20	°C
Number of isolation valves	3	
Pump to service water line	Final design	

Option 2

- Accumulator		
Volume	3000	dm^3
Pressure	4.0	MPa
pressure when empty	0.8	MPa
Water temperature	20	°C
Helium gas bottle pressure	20	MPa
Number of helium bottles	8	
Number of pressure regulators	8	
Number of gas valves	2	
Number of isolation valves (Power op.)	1	
Number of check valves	1	

2.5 Feed and Bleed System

Maximum feed flow	55	cm^3/s
Maximum bleed flow	100	cm^3/s
Pump head	50	m
Number of isolation valves	2	

2.6 Non Condensibles Injection System

The non condensible injection system is injecting upstream of the ECI outlet header isolation valve and consists of a helium bottle manually serviced. The connection to the ECI line is made through an isolation valve.

Gas	helium	
Pressure	20	MPa
Number of isolation valves	2	

2.7 Service Water System

The service water system is location dependent. Nevertheless the following constitutes a minimum requirement for one day of experimentation, assuming that the outlet service water is not recycled.

Accumulator volume	25	m^3
Flow rate	20	dm^3/s
Pressure	100	kPa
Water temperature	20	°C

3. Instrumentation

Instrumentation has been specified in the previous section (Instrumentation). The following is the list of instrumentation that is required

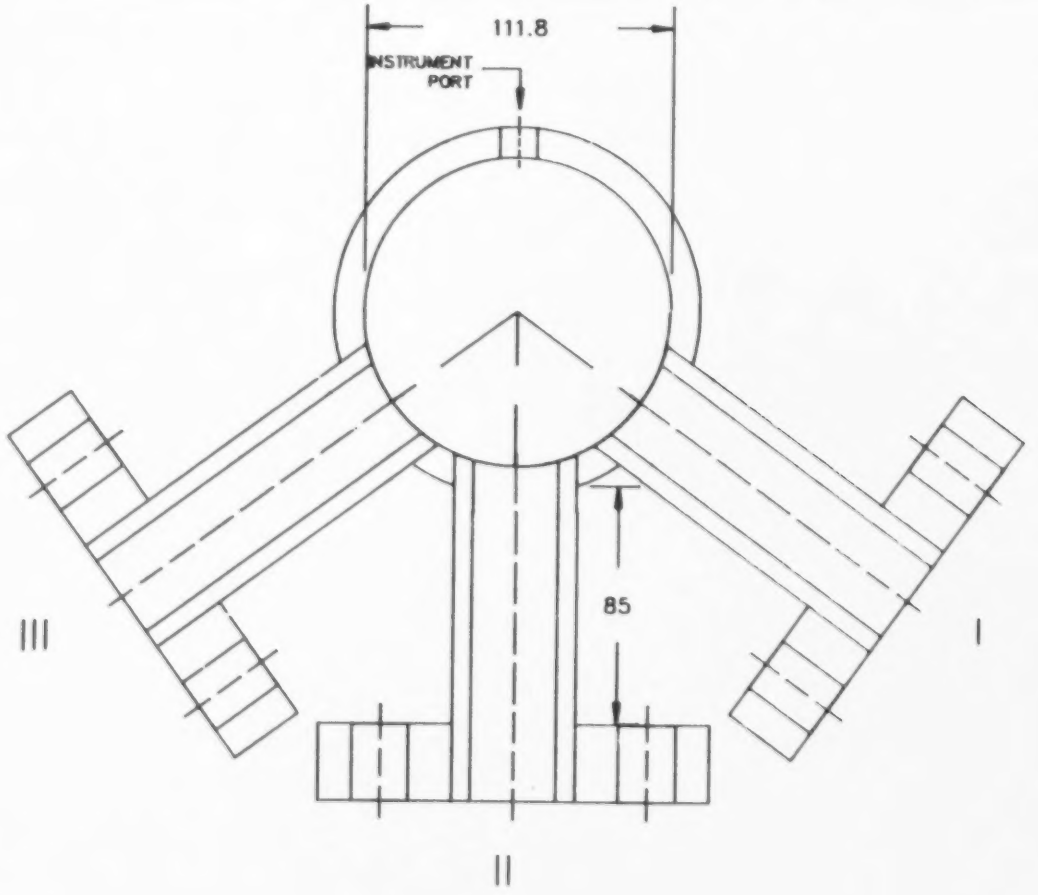
Thermocouples	229
Absolute pressure transducers	29
Differential pressure transducers	32
Flow meters	20
Power transducers	25
Void meters	6

4. Data Acquisition

The data acquisition specifications can be found in the instrumentation section.

5. Insulation

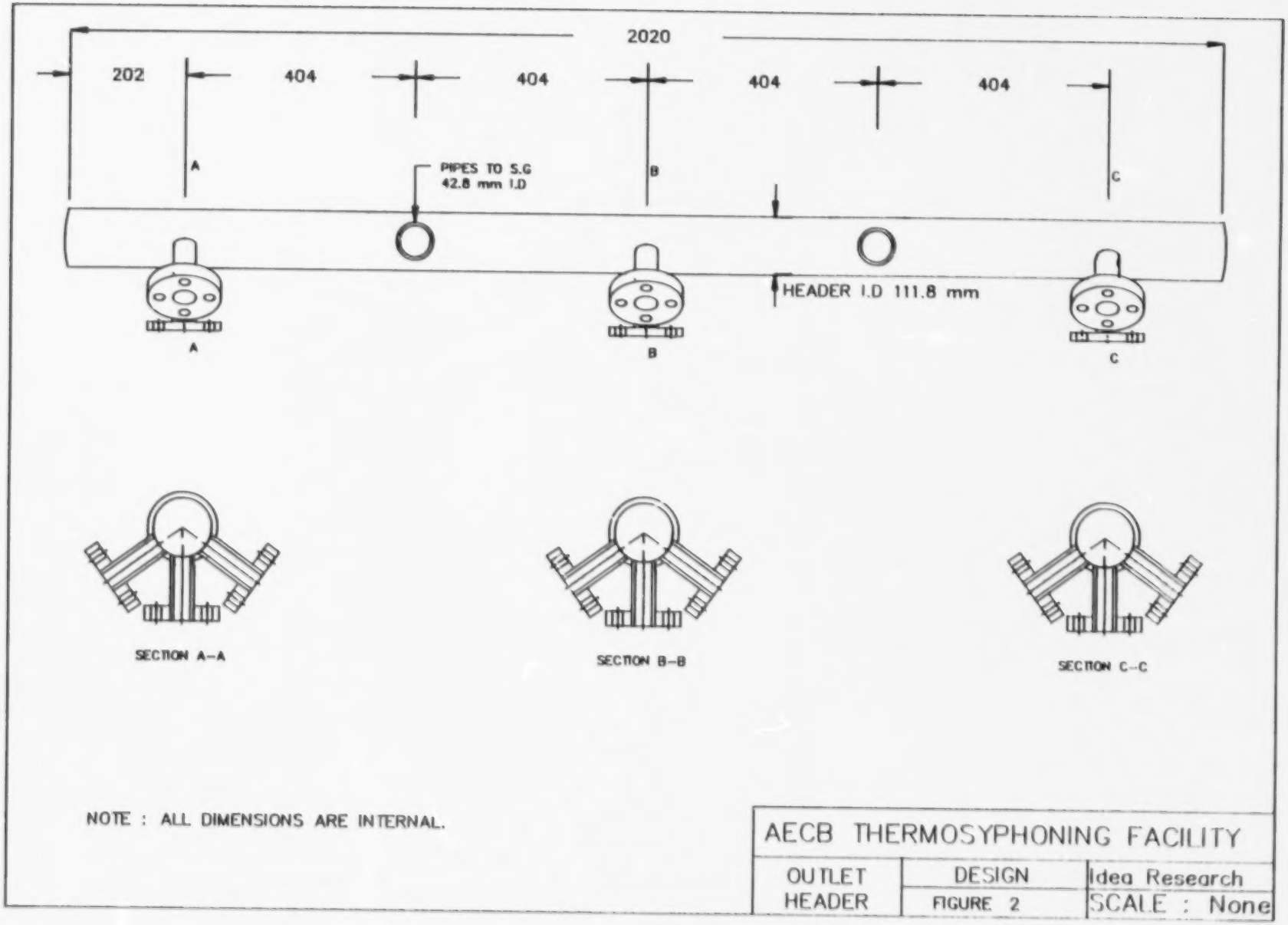
The insulation of the facility must be such as not more than 10% of heat losses occur in the primary system. The steam generators may not need such an insulation, but it is necessary to be able to evaluate their heat losses for heat balance purposes.



CROSS SECTIONAL VIEW AT FEEDER LOCATIONS

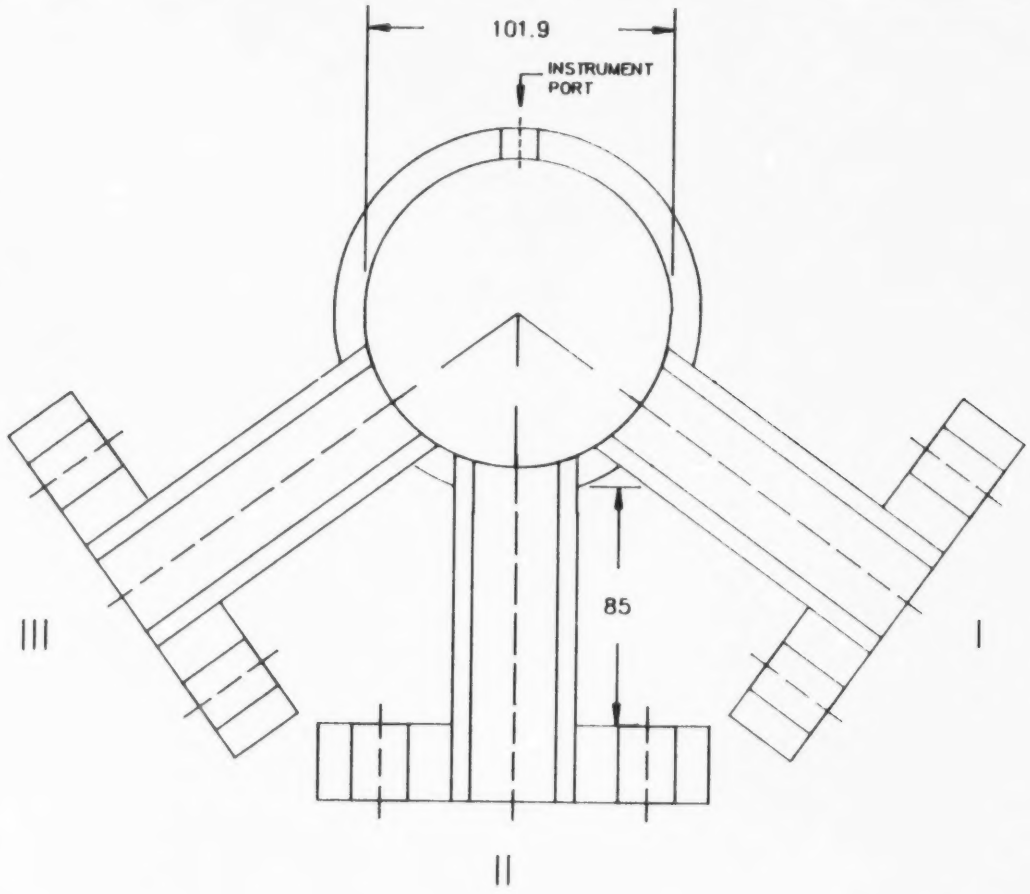
NOTE : ALL FLANGES ARE 3/4" 1500 lb.
: PIPE DIAMETERS CORRESPOND TO FEEDERS.

AECB THERMOSYPHONING FACILITY		
OUTLET HEADER	DESIGN	Idea Research
	FIGURE 1	SCALE : None



NOTE : ALL DIMENSIONS ARE INTERNAL.

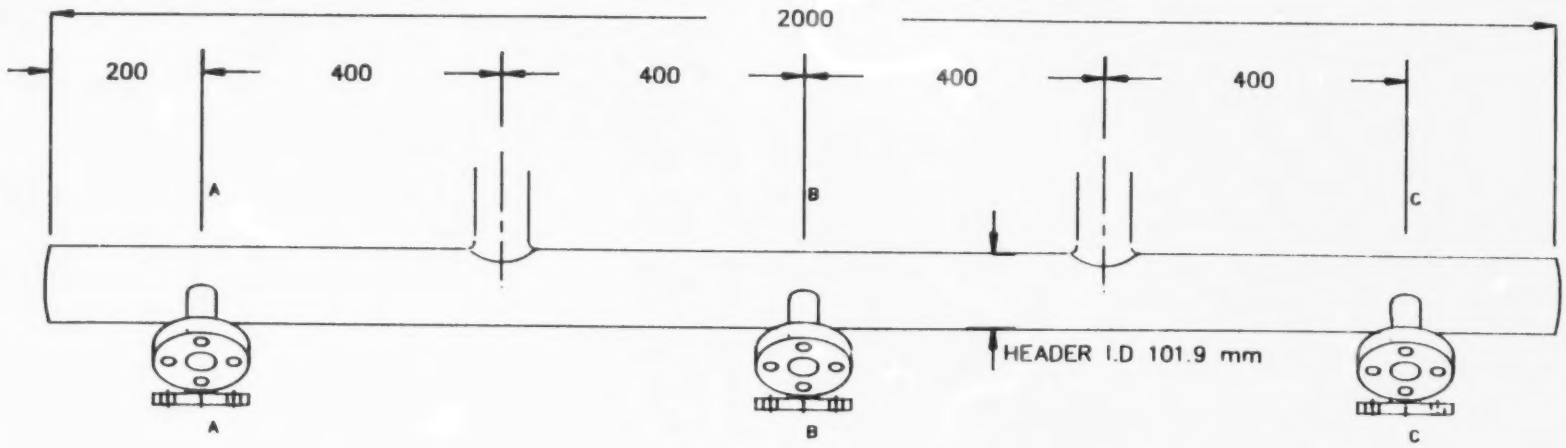
AECB THERMOSYPHONING FACILITY		
OUTLET HEADER	DESIGN	Idea Research
	FIGURE 2	SCALE : None

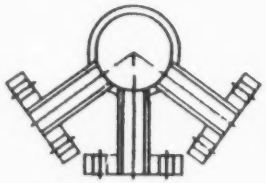


CROSS SECTIONAL VIEW AT FEEDER LOCATIONS

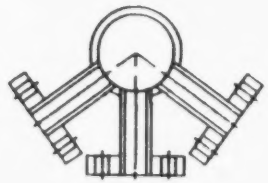
NOTE : ALL FLANGES ARE 3/4" 1500 lb.
: PIPE DIAMETERS CORRESPOND TO FEEDERS.

AECB THERMOSYPHONING FACILITY		
INLET HEADER	DESIGN	Idea Research
	FIGURE 3	SCALE : NONE

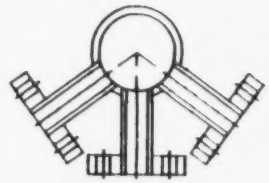




SECTION A–A



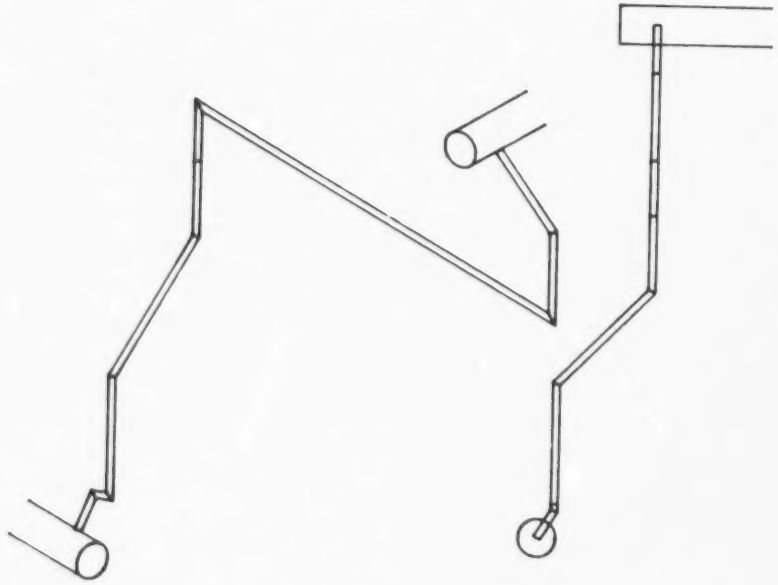
SECTION B–B



SECTION C–C

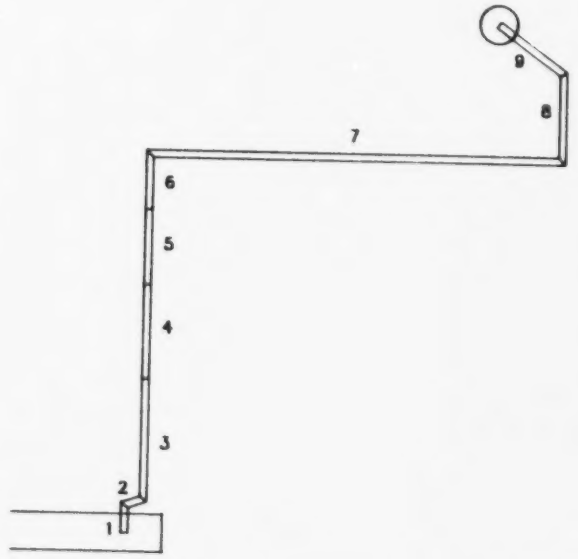
NOTE : ALL DIMENSIONS ARE INTERNAL.

AECB THERMOSYPHONING FACILITY		
INLET HEADER	DESIGN	Idea Research
	FIGURE 4	SCALE : None



XYZ ISOMETRIC

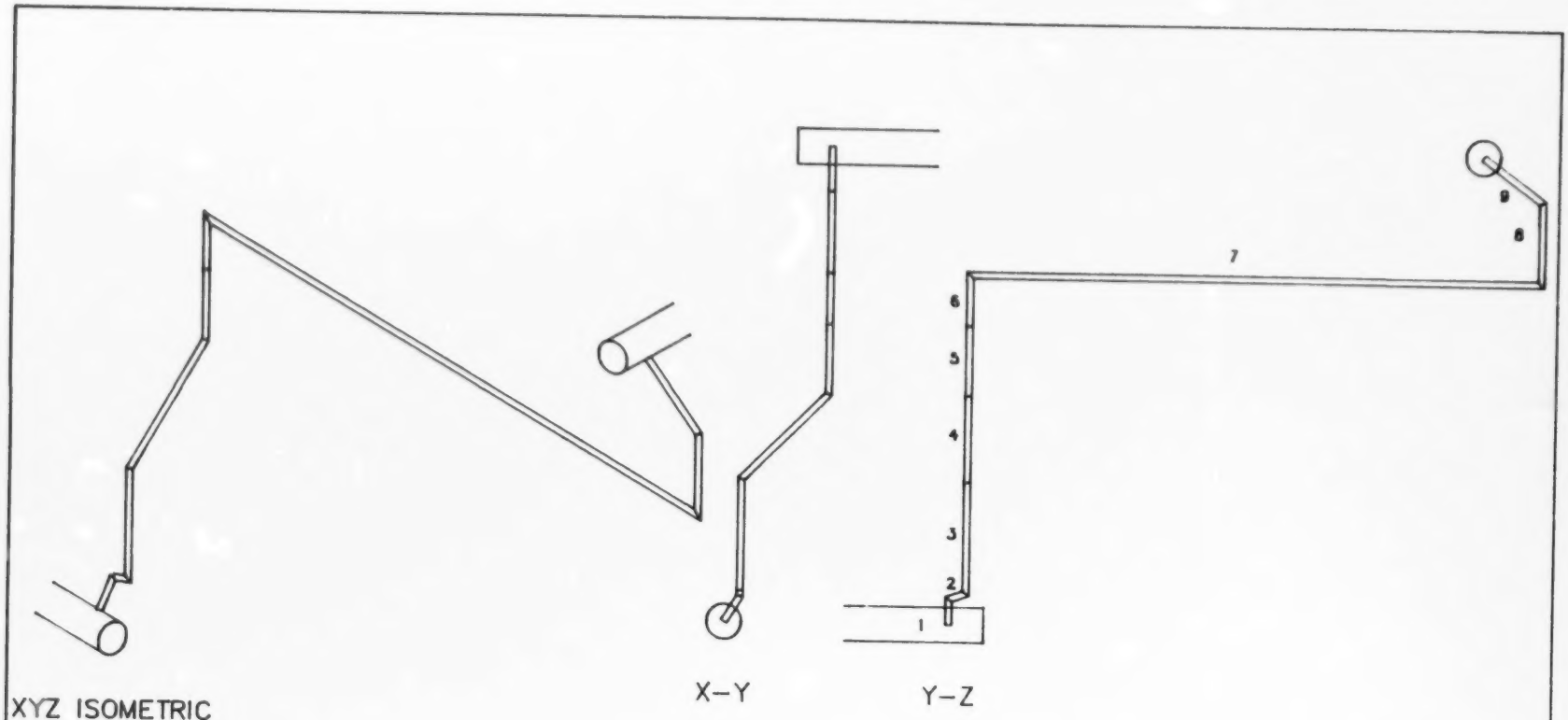
X–Y



Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A1–1	DESIGN	IDEA Research
	FIGURE 5	



XYZ ISOMETRIC

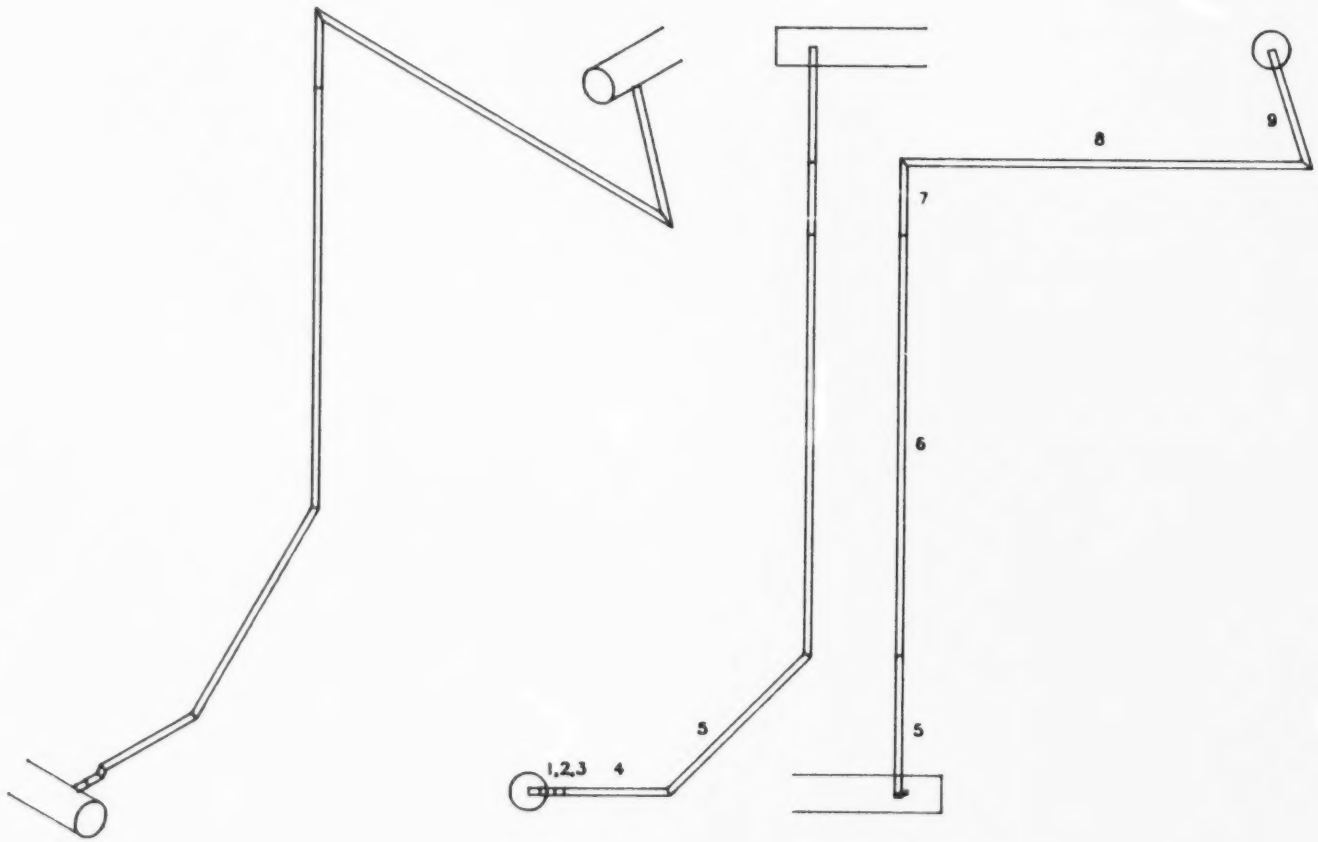
X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A1–0	DESIGN	
	FIGURE 6	IDEA Research

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

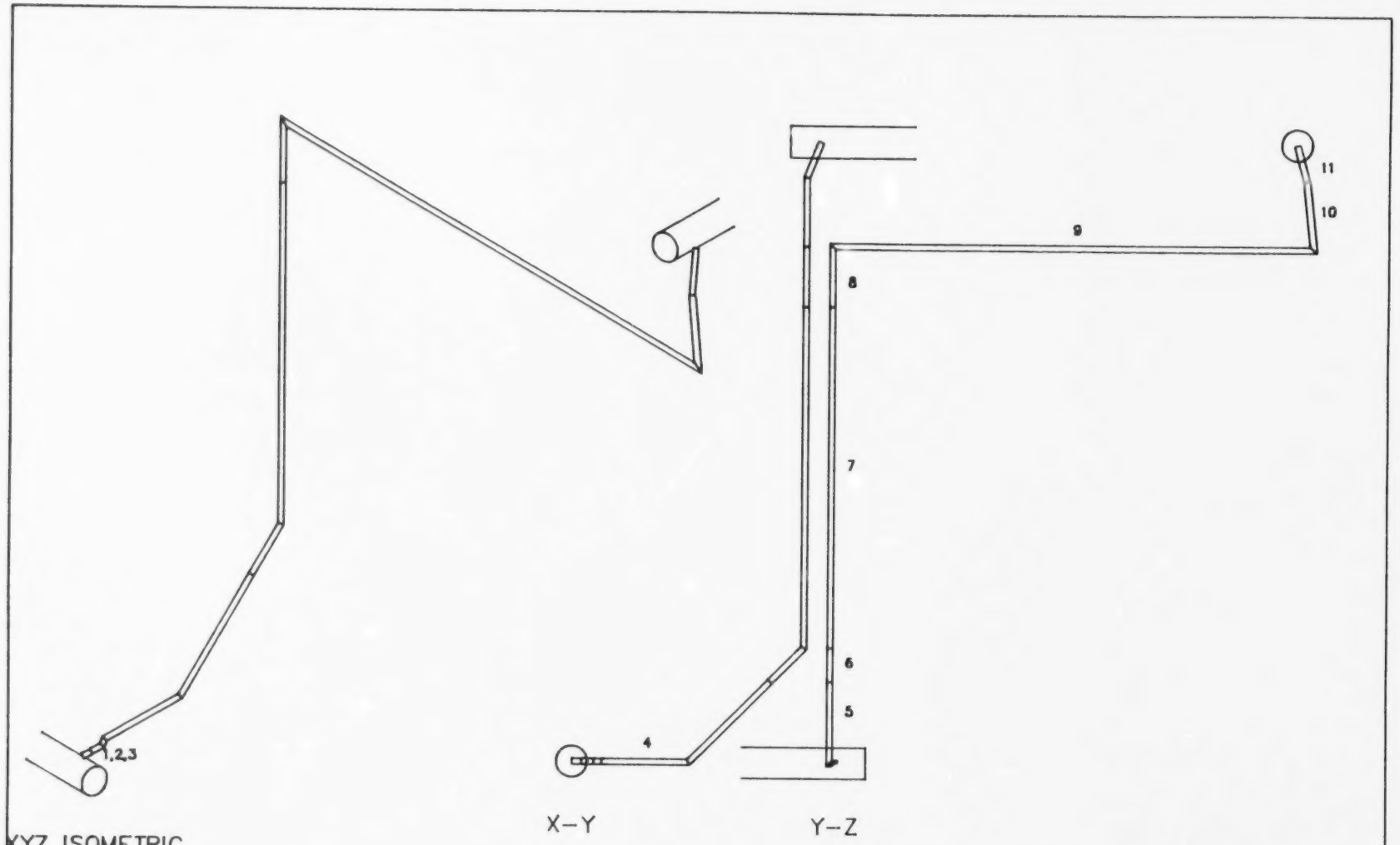


XYZ ISOMETRIC

X–Y

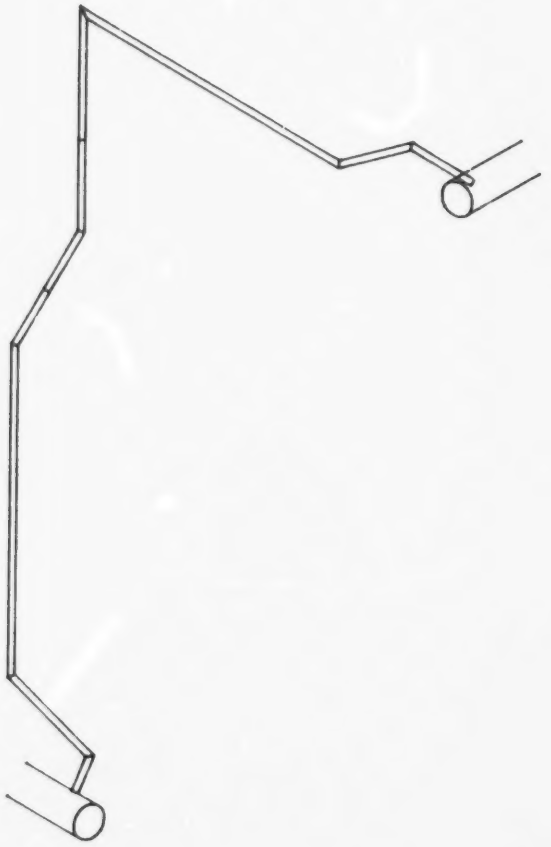
Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A2–1	DESIGN	IDEA Research
	FIGURE 7	

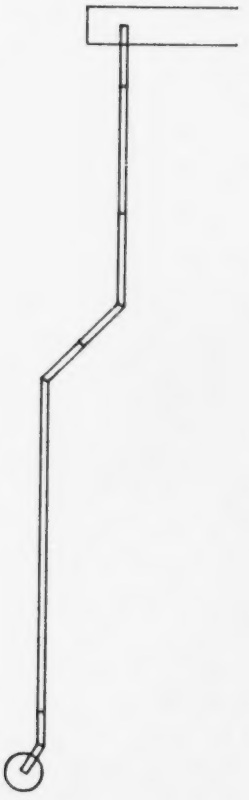


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

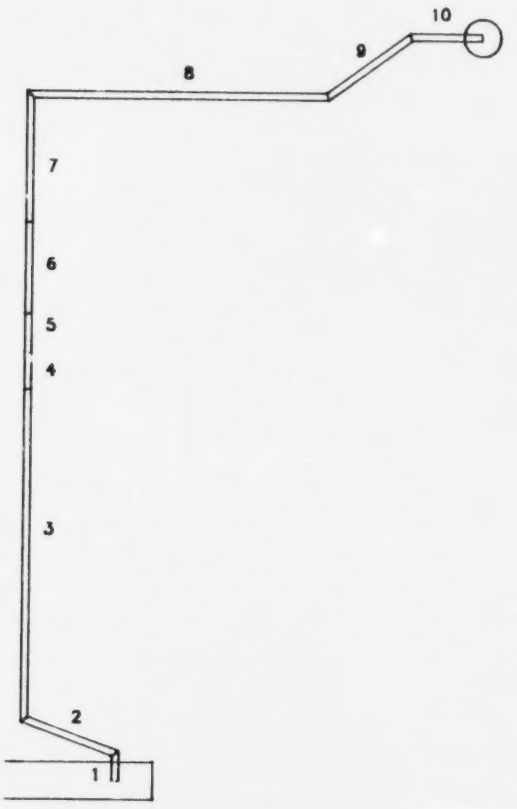
AECB THERMOSYPHONING FACILITY		
FEEDER A2–0	DESIGN	IDEA Research
	FIGURE 8	



XYZ ISOMETRIC



X–Y

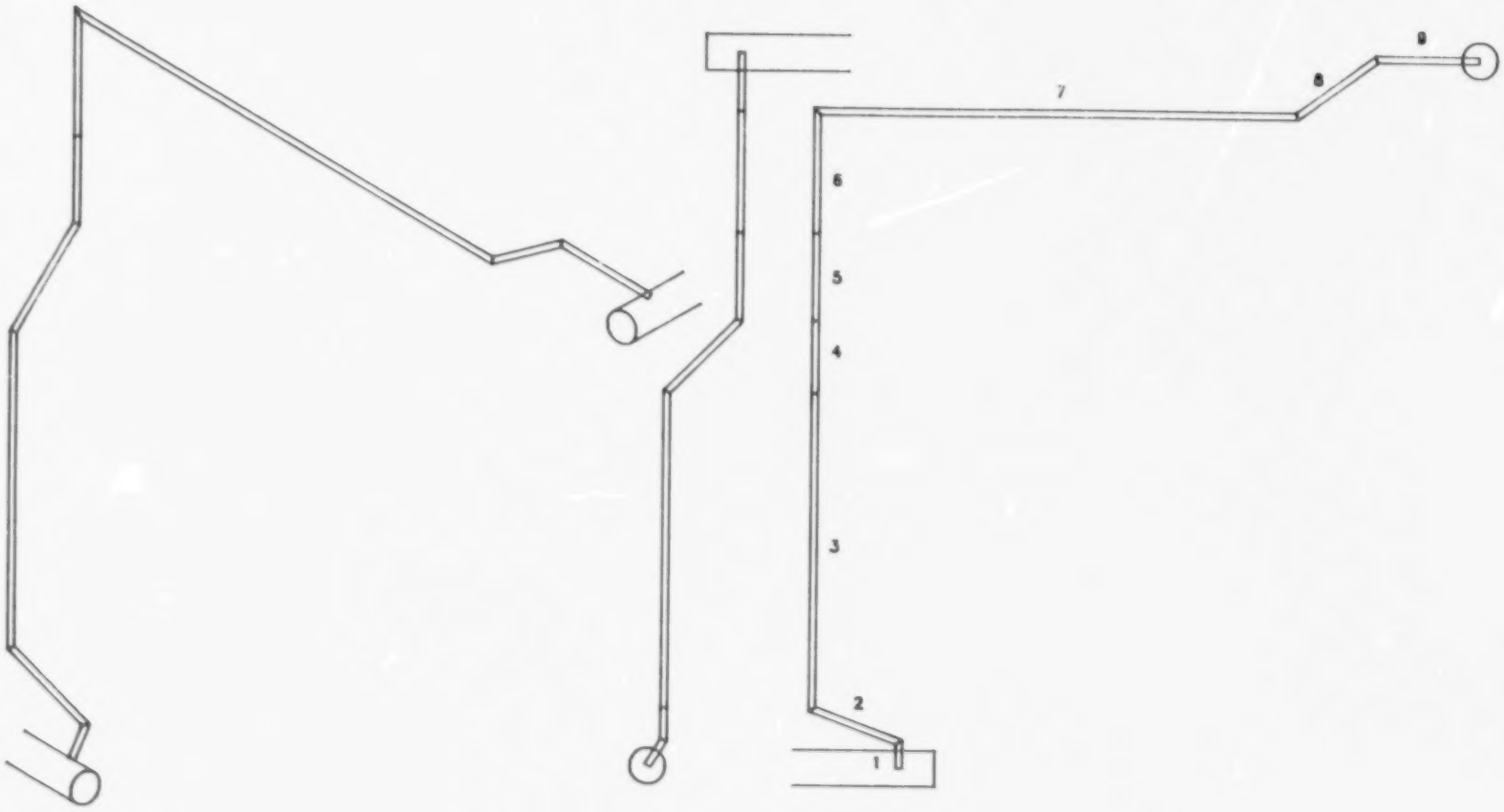


Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY

FEEDER A3–1	DESIGN	IDEA Research
	FIGURE 9	



XYZ ISOMETRIC

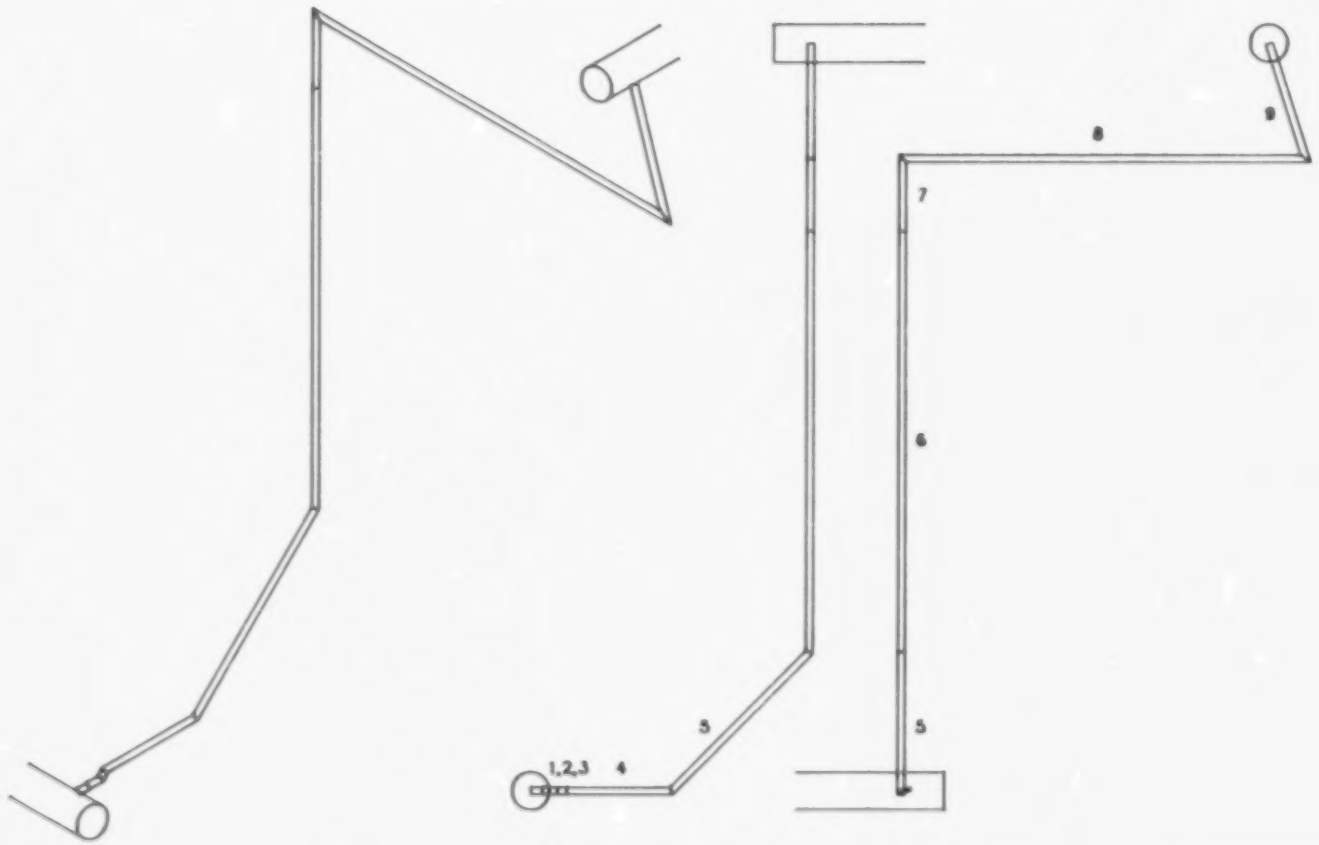
X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A3–0	DESIGN	IDEA Research
	FIGURE 10	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

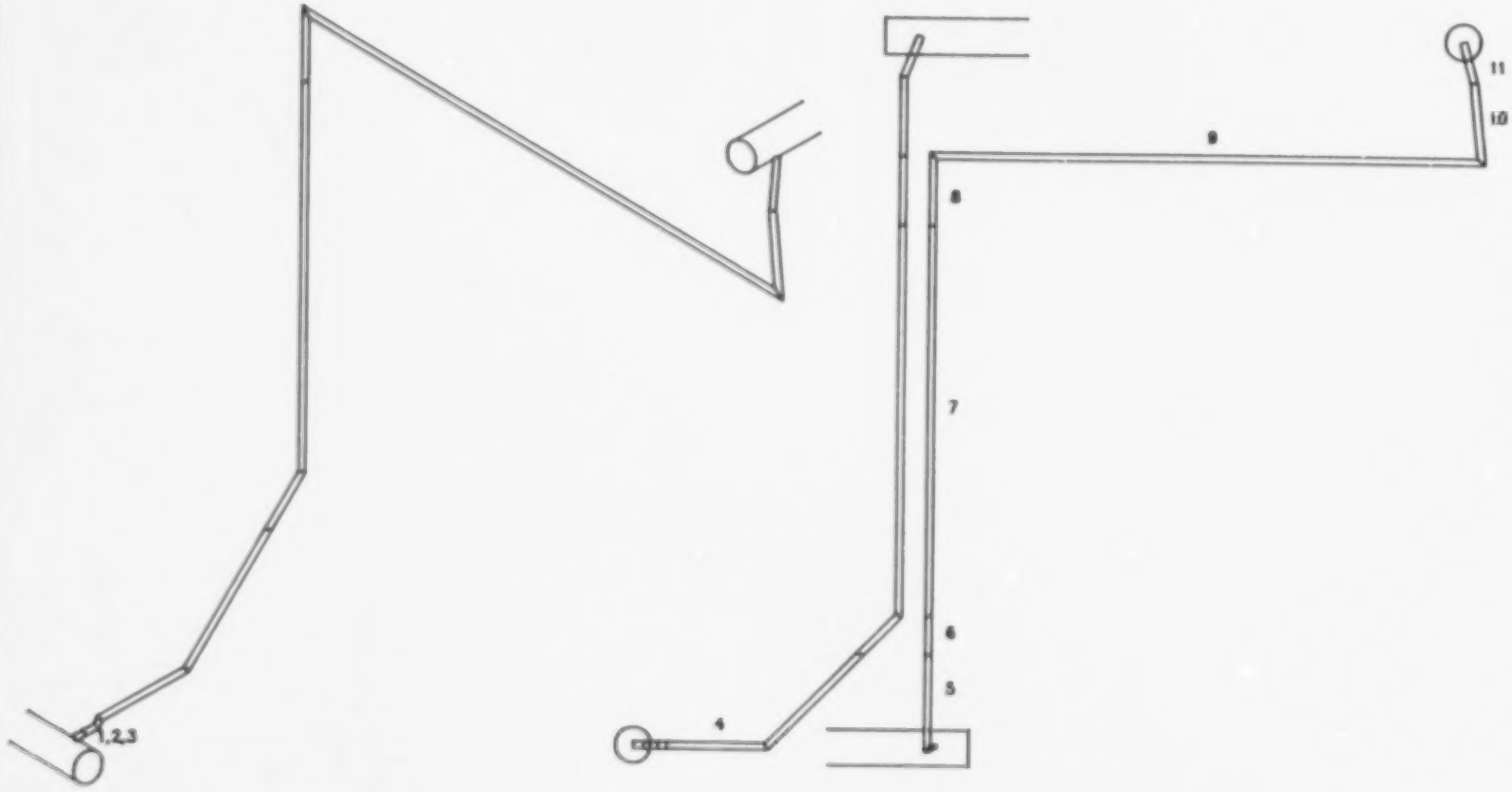


XYZ ISOMETRIC

X–Y

Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A4–1	DESIGN	IDEA Research
	FIGURE 11	



KYZ ISOMETRIC

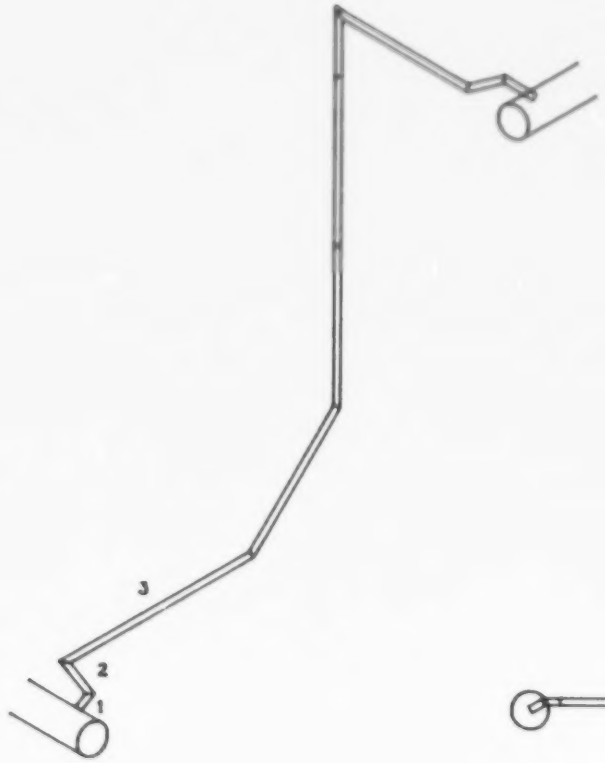
X–Y

Y–Z

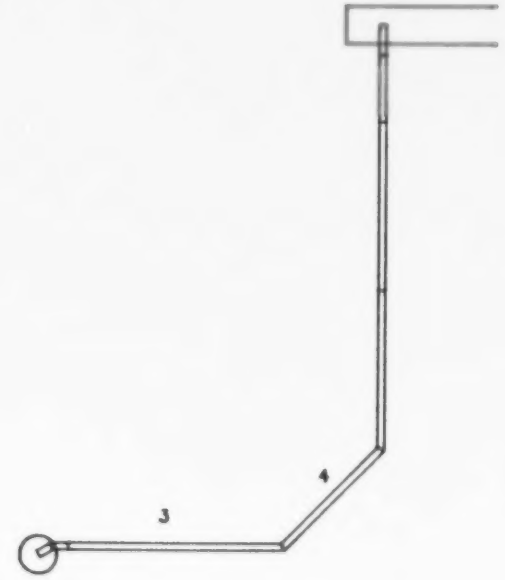
X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER A4–0	DESIGN	IDEA Research
	FIGURE 12	

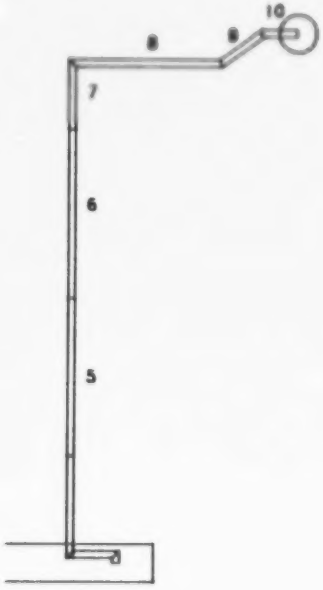
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC



X-Y



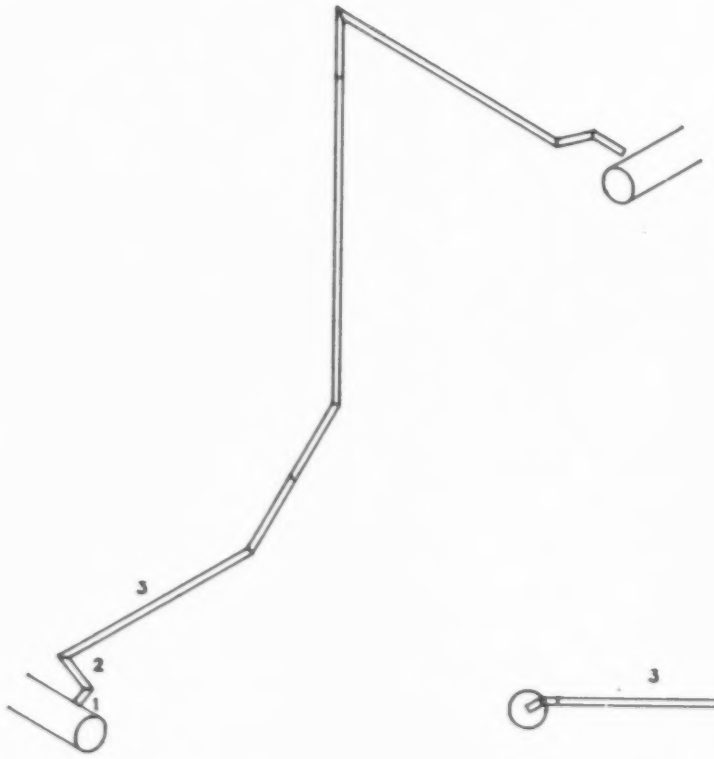
Y-Z

X-PERPENDICULAR TO CHANNEL Y-VERTICAL Z-ALONG CHANNEL AXIS

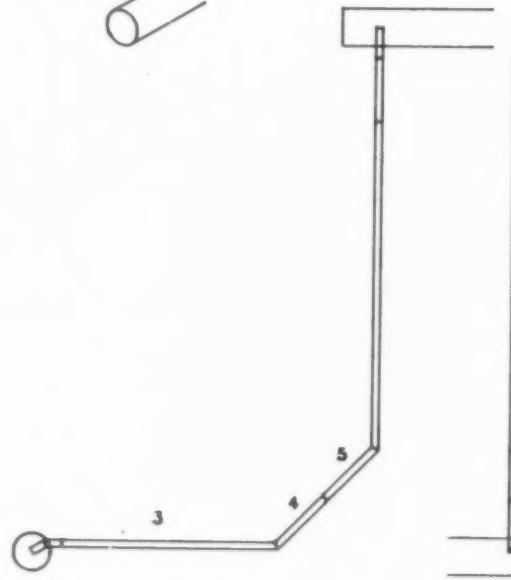
AECB THERMOSYPHONING FACILITY		
FEEDER A5-1	DESIGN	IDEA Research
	FIGURE 13	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

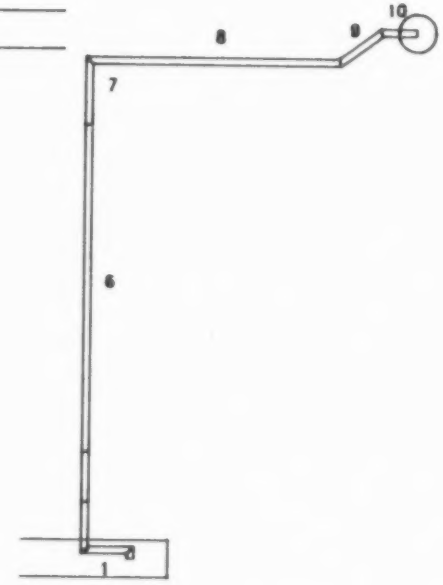
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC

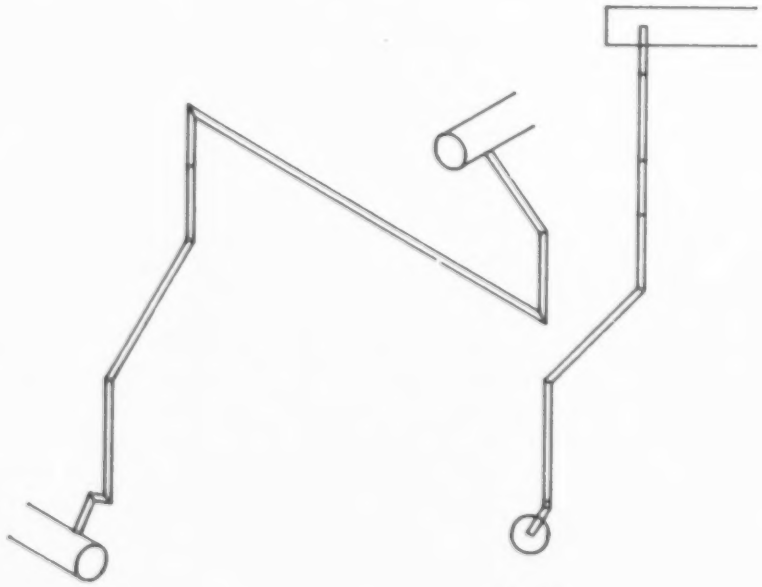


X–Y



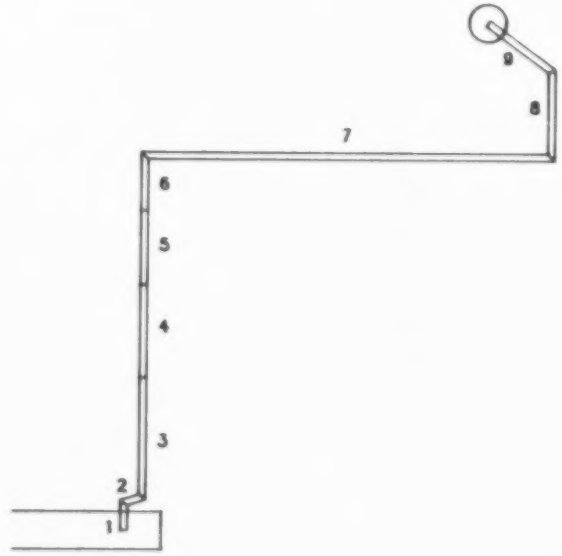
Y–Z

AECB THERMOSYPHONING FACILITY		
FEEDER A5–0	DESIGN	IDEA Research
	FIGURE 14	



XYZ ISOMETRIC

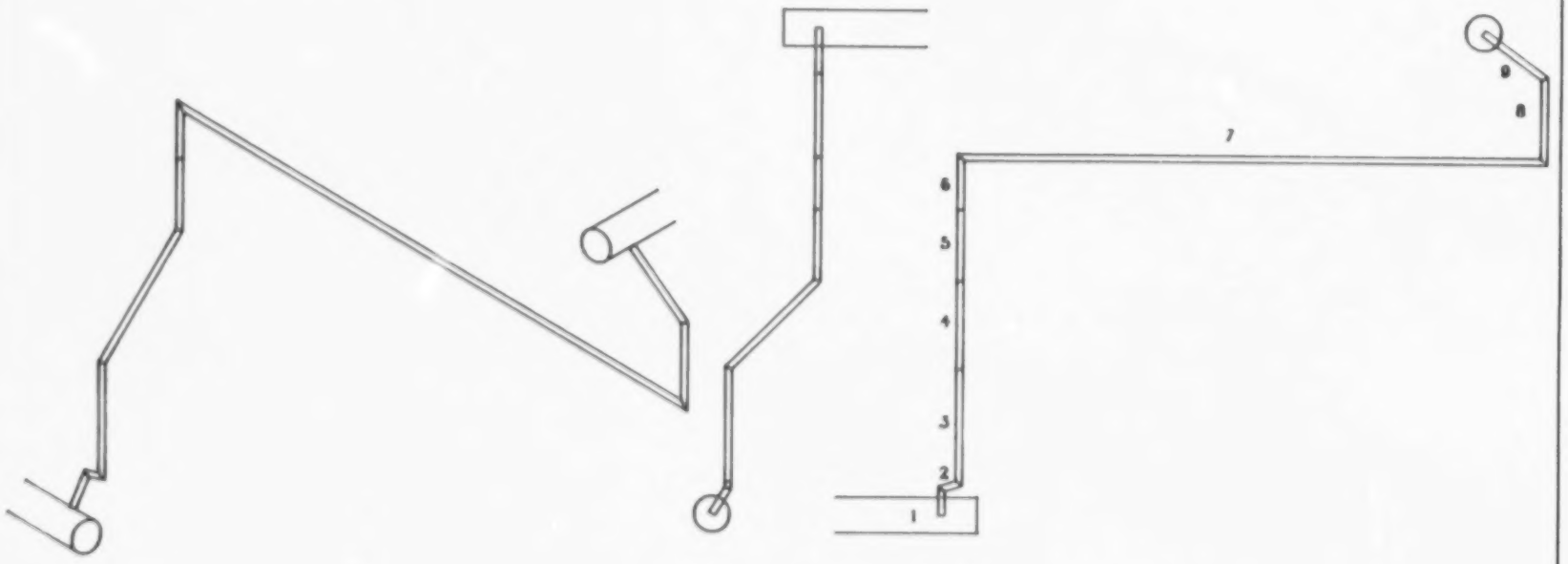
X–Y



Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B1–1	DESIGN	IDEA Research
	FIGURE 15	



XYZ ISOMETRIC

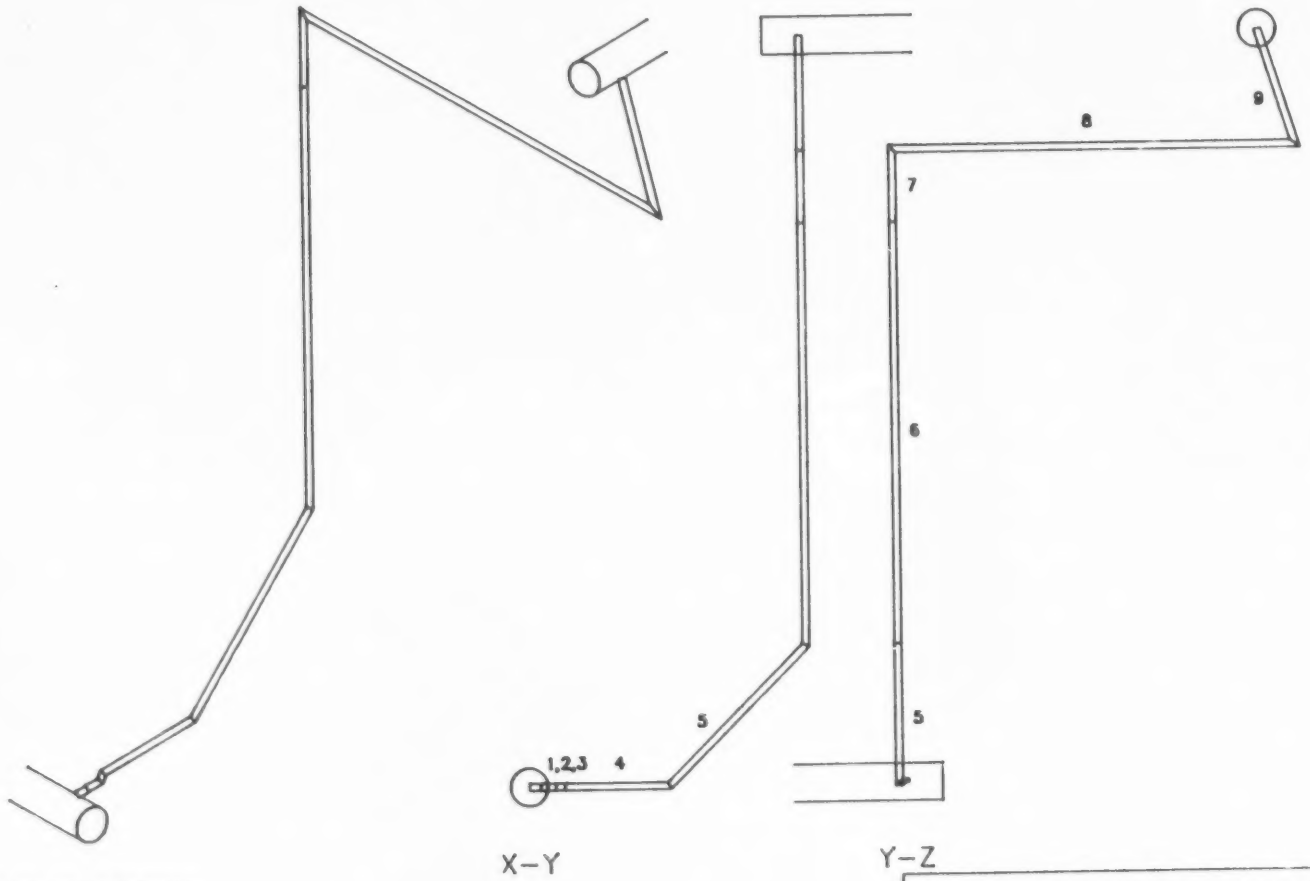
X–Y

Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B1–0	DESIGN	
	FIGURE 16	IDEA Research

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS



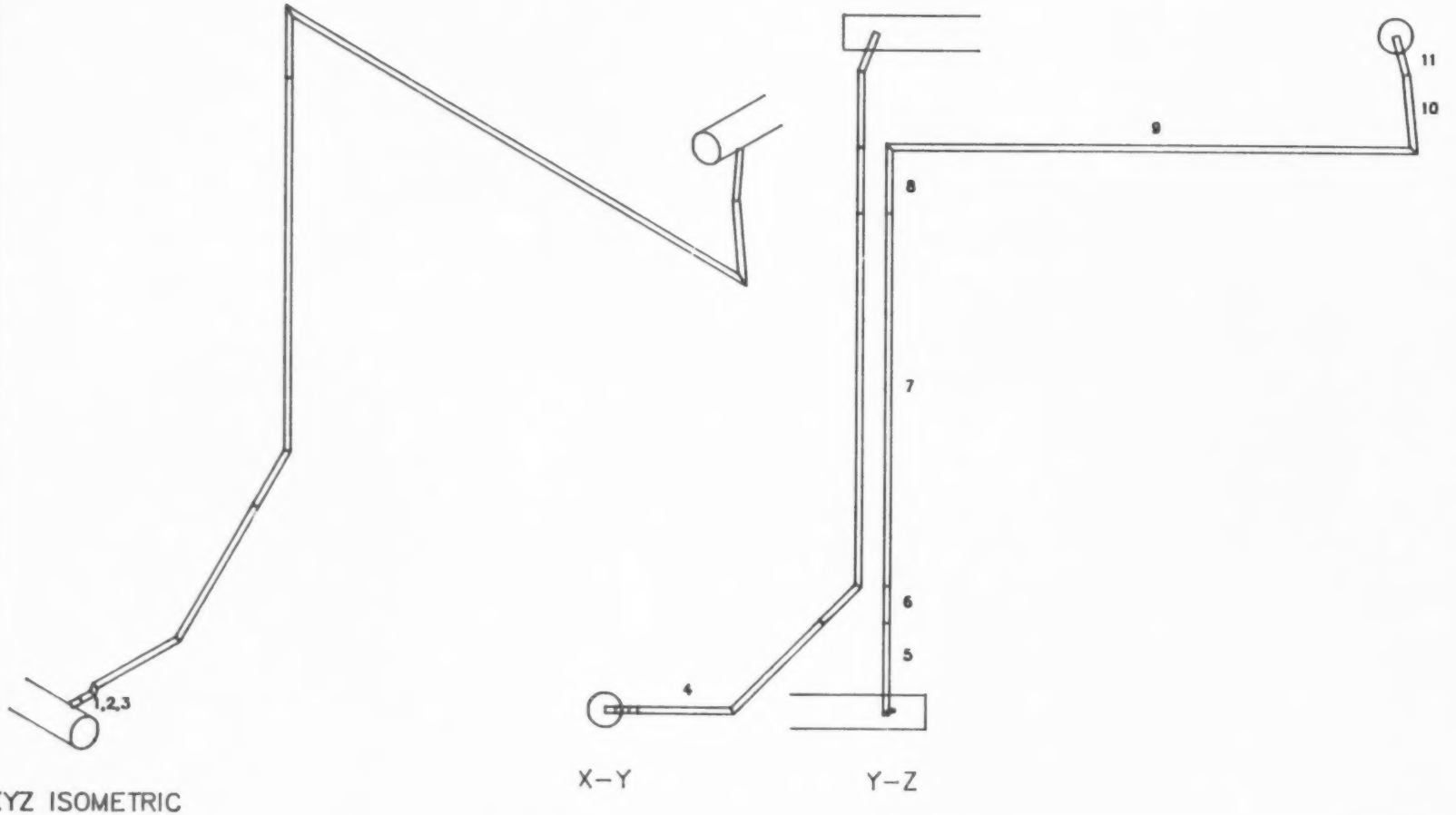
XYZ ISOMETRIC

X–Y

Y–Z

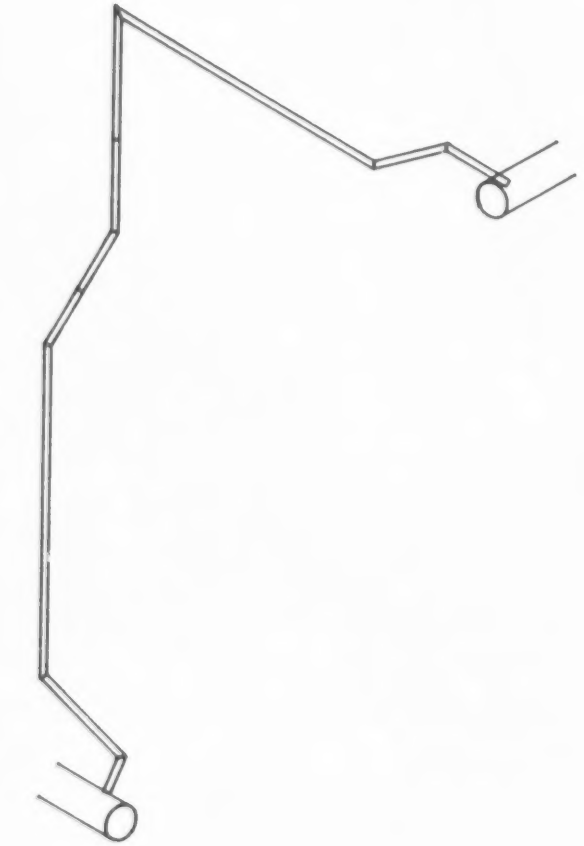
AECB THERMOSYPHONING FACILITY

FEEDER B2–I	DESIGN	IDEA Research
	FIGURE 17	

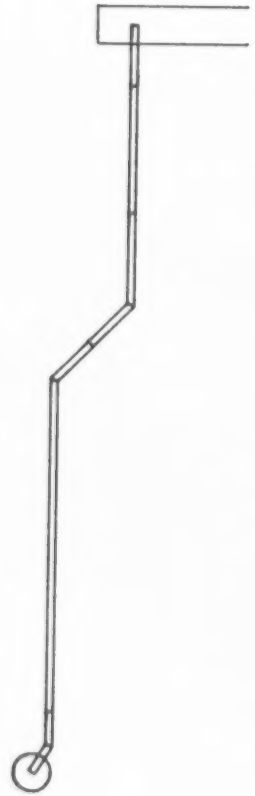


X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

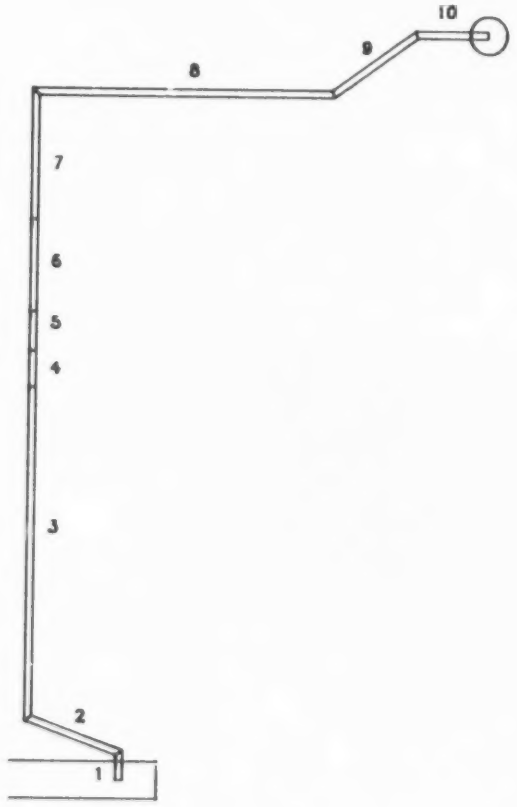
AECB THERMOSYPHONING FACILITY		
FEEDER B2–0	DESIGN	IDEA Research
	FIGURE 18	



XYZ ISOMETRIC



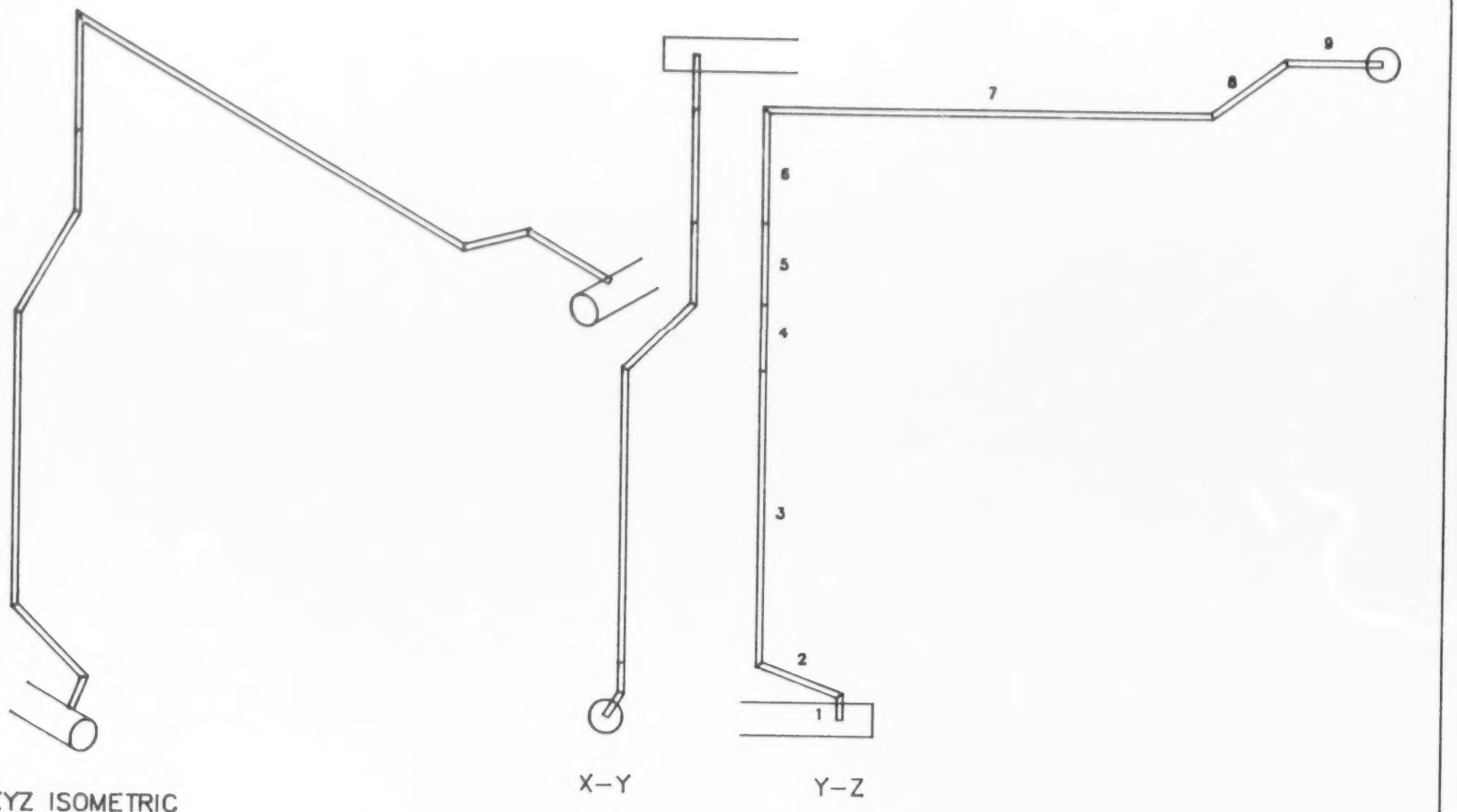
X–Y



Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

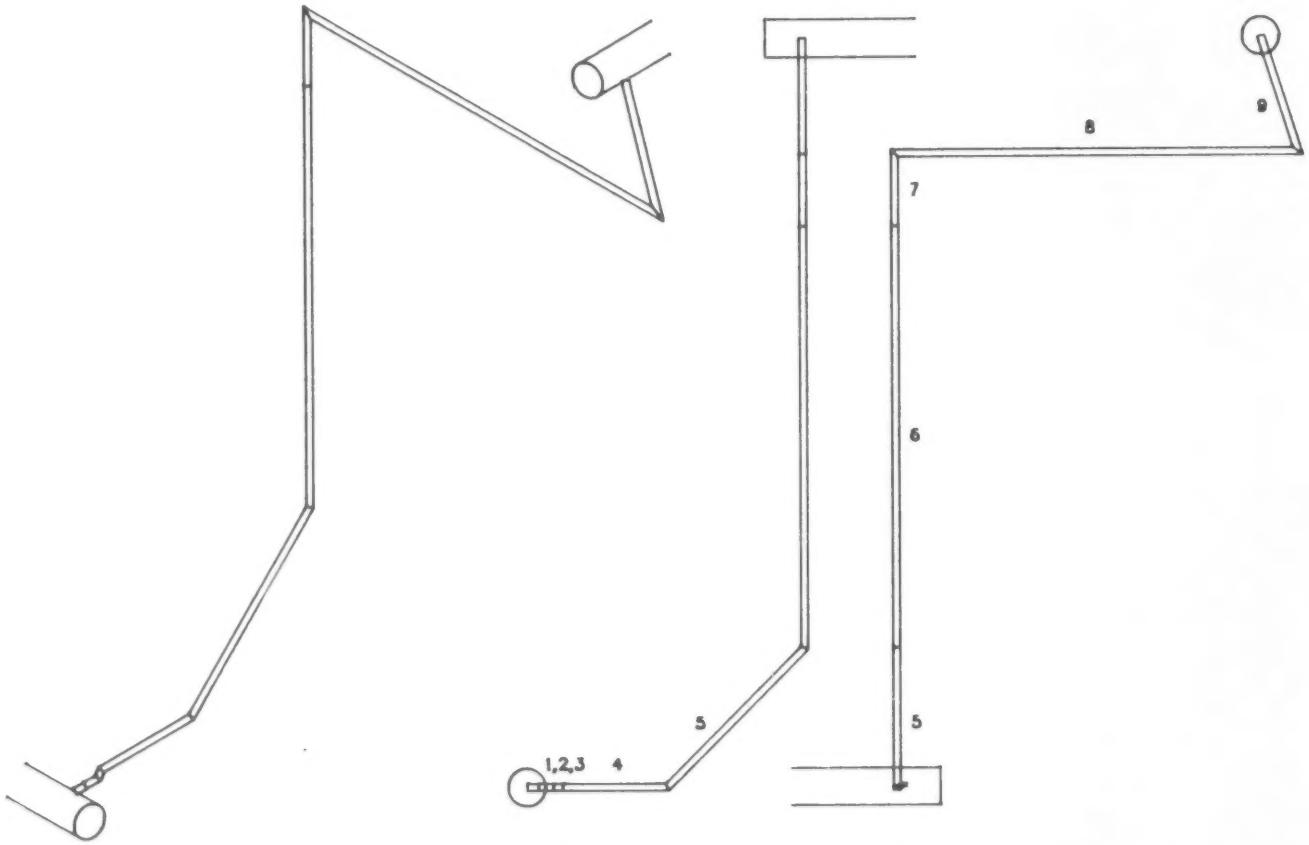
AECB THERMOSYPHONING FACILITY		
FEEDER B3–1	DESIGN	IDEA Research
	FIGURE 19	



X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B3–0	DESIGN	IDEA Research
	FIGURE 20	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

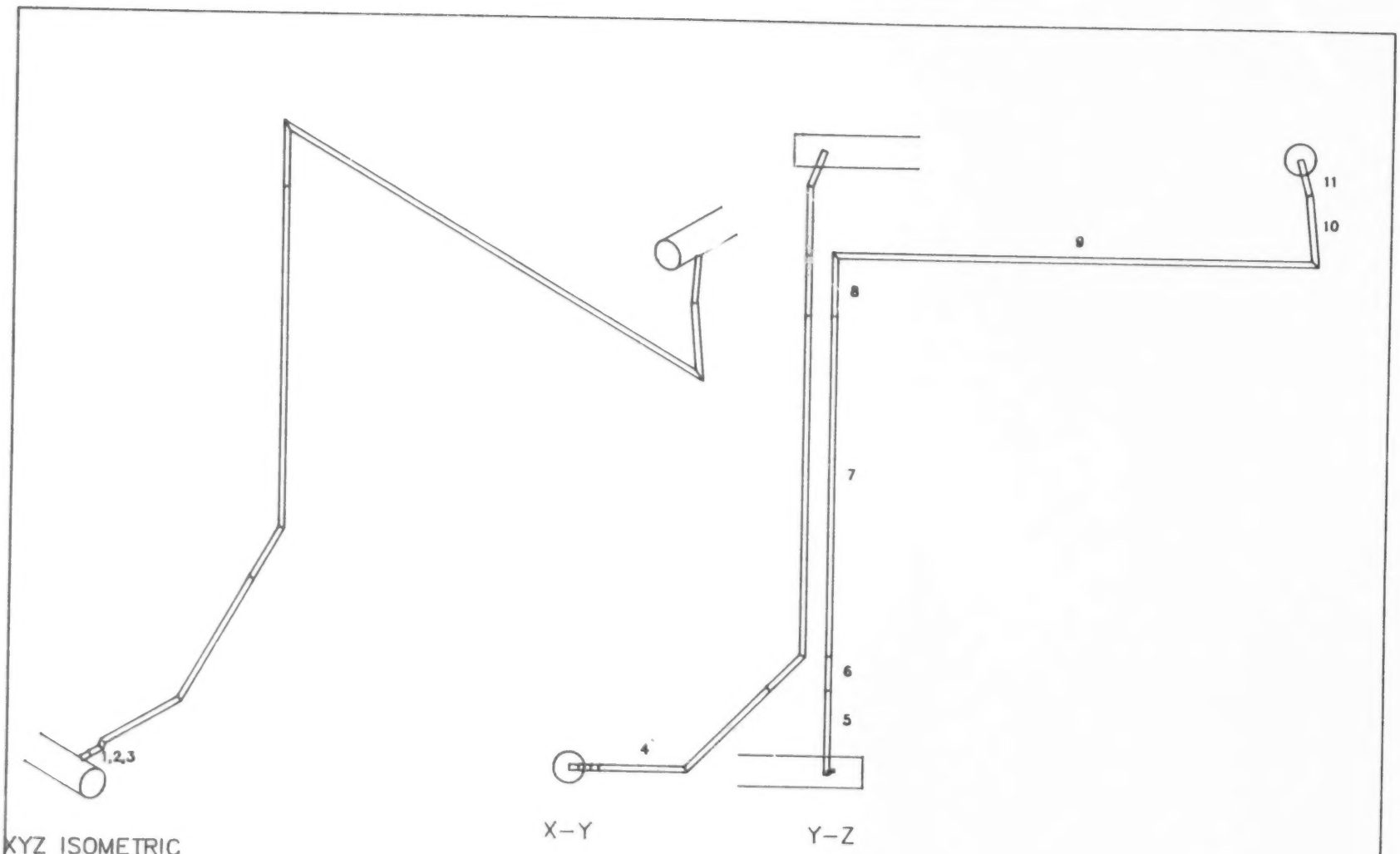


XYZ ISOMETRIC

X–Y

Y–Z

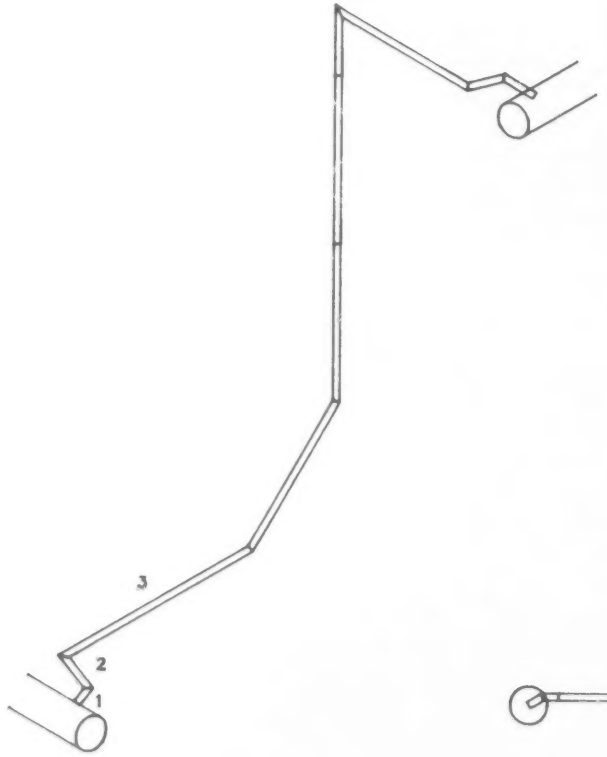
AECB THERMOSYPHONING FACILITY		
FEEDER B4–I	DESIGN	IDEA Research
	FIGURE 21	



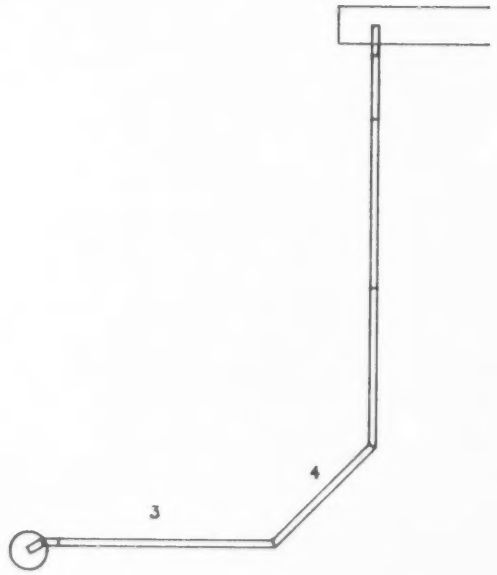
X-PERPENDICULAR TO CHANNEL Y-VERTICAL Z-ALONG CHANNEL AXIS

AECB THERMOSYPHONING FACILITY		
FEEDER B4-0	DESIGN	IDEA Research
	FIGURE 22	

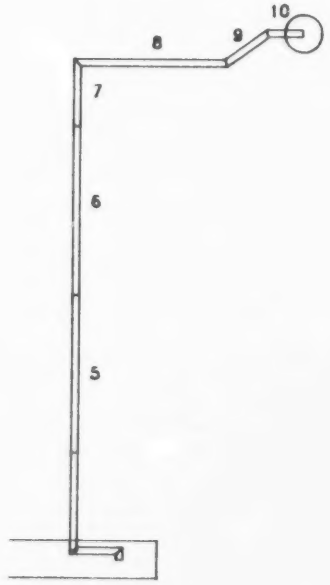
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC



X–Y



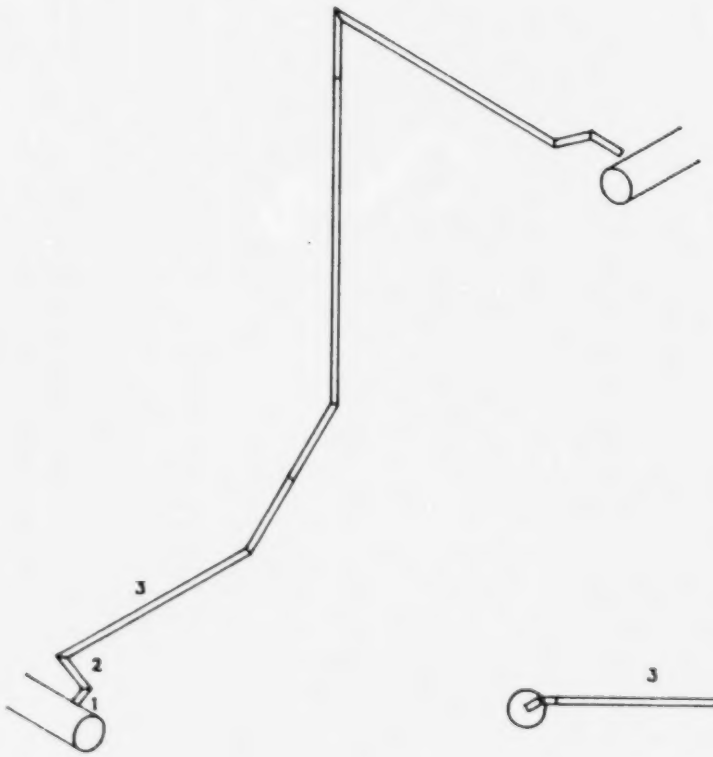
Y–Z

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

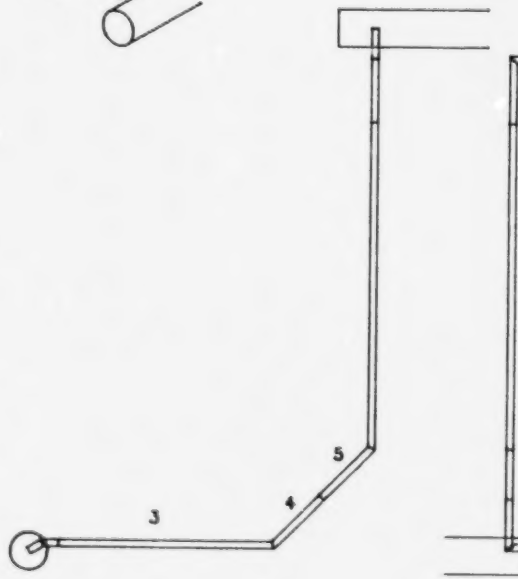
AECB THERMOSYPHONING FACILITY		
FEEDER B5–1	DESIGN	IDEA Research
	FIGURE 23	

X–PERPENDICULAR TO CHANNEL Y–VERTICAL Z–ALONG CHANNEL AXIS

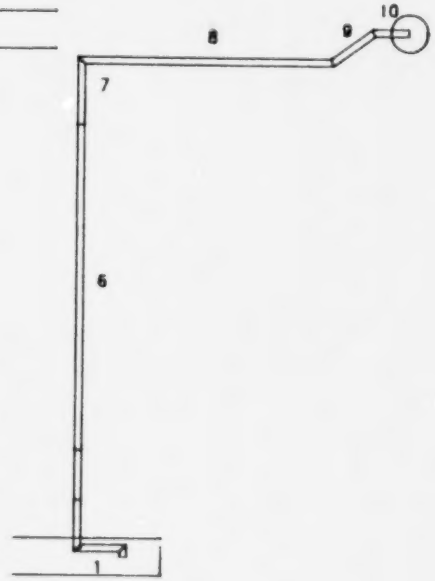
NOTE : THIS FEEDER DRAWN AT HALF THE SCALE OF OTHER 4 FEEDERS.



XYZ ISOMETRIC

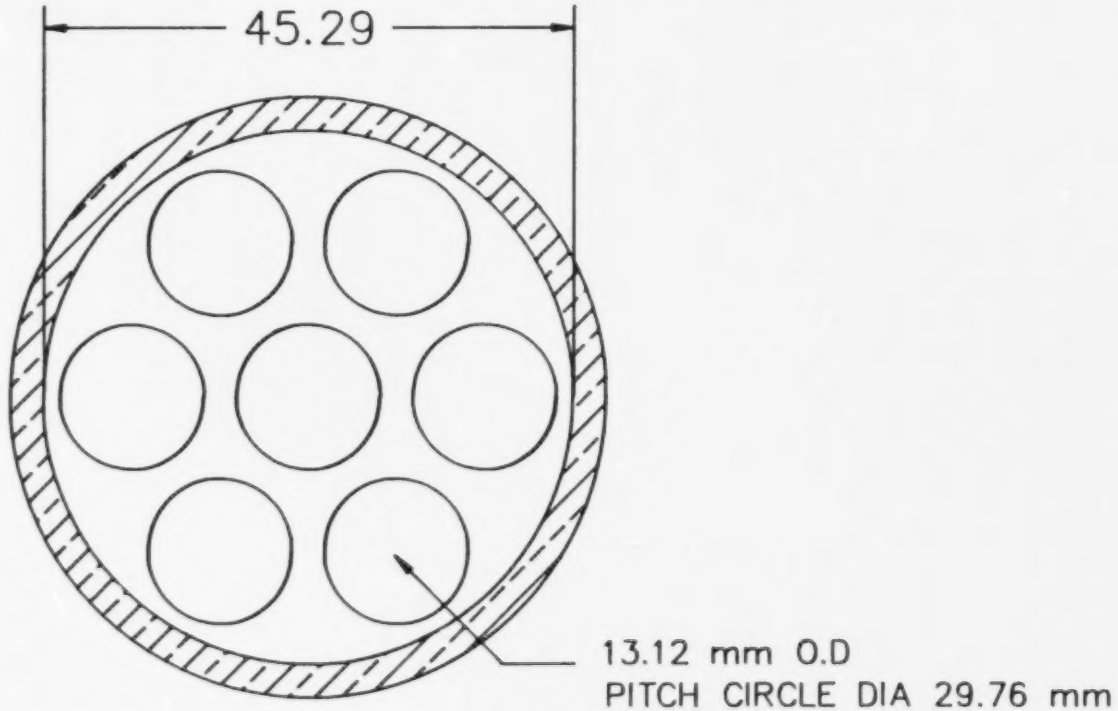


X–Y

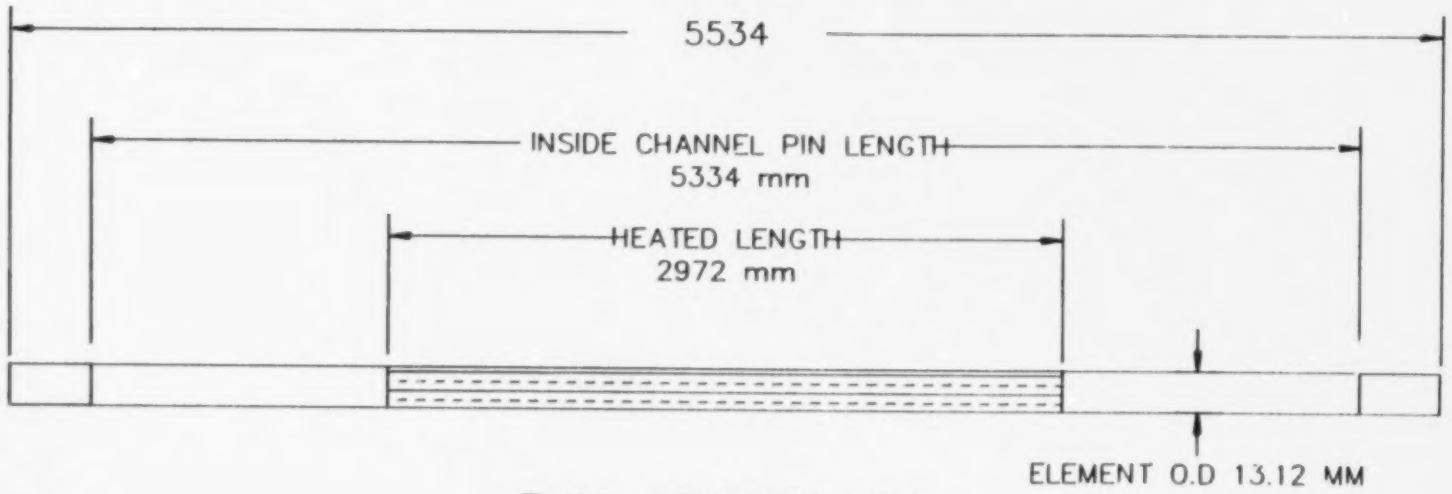


Y–Z

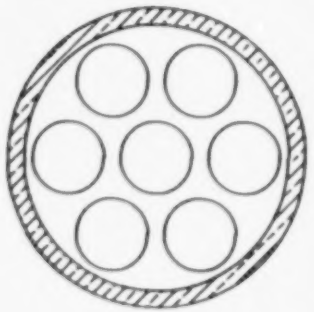
AECB THERMOSYPHONING FACILITY		
FEEDER B5–0	DESIGN	IDEA Research
	FIGURE 24	



AECB THERMOSYPHONING FACILITY		
BUNDLE SECTION	DESIGN	IDEA Research
	FIGURE 25	

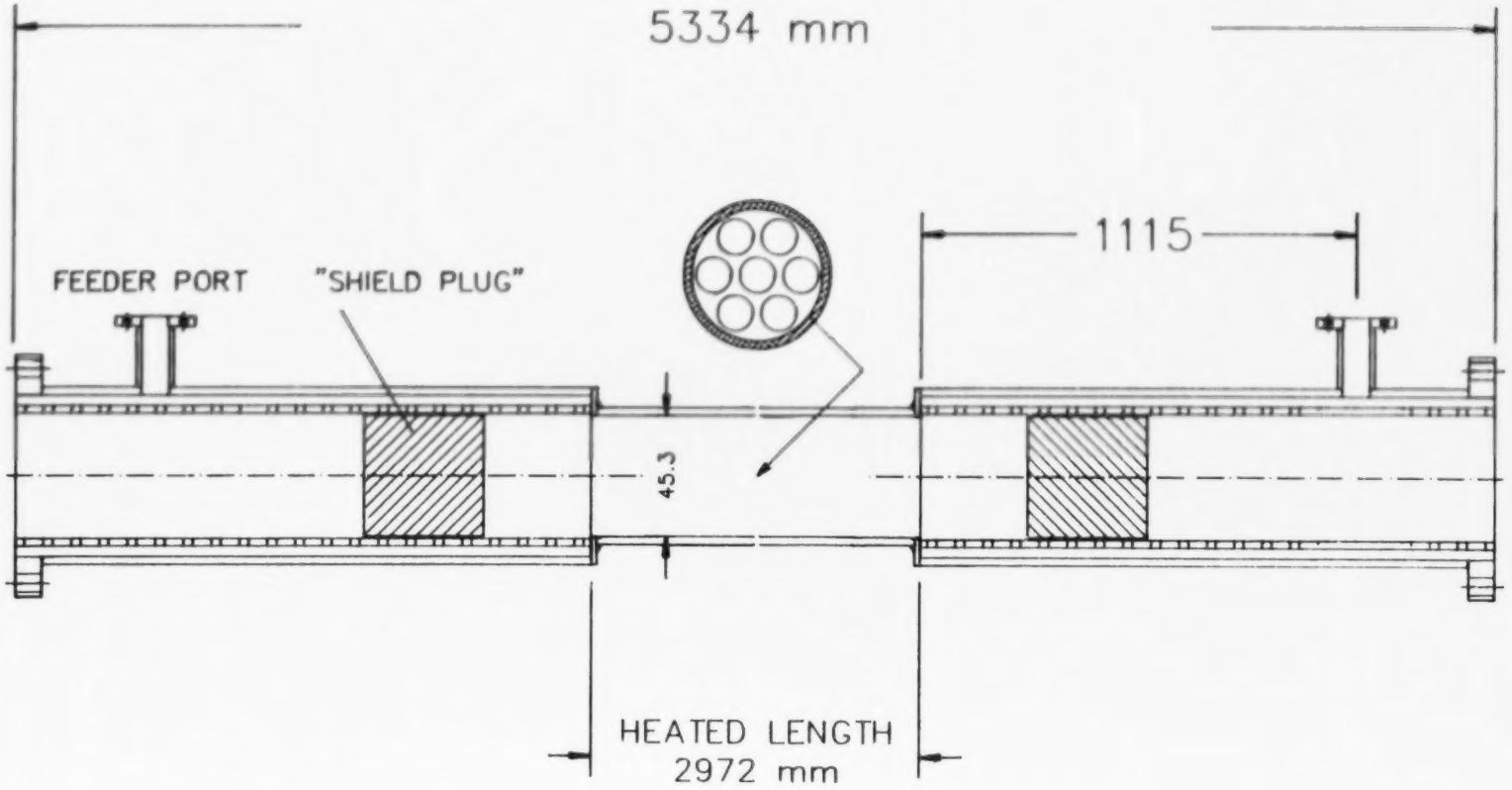


FULL LENGTH PIN

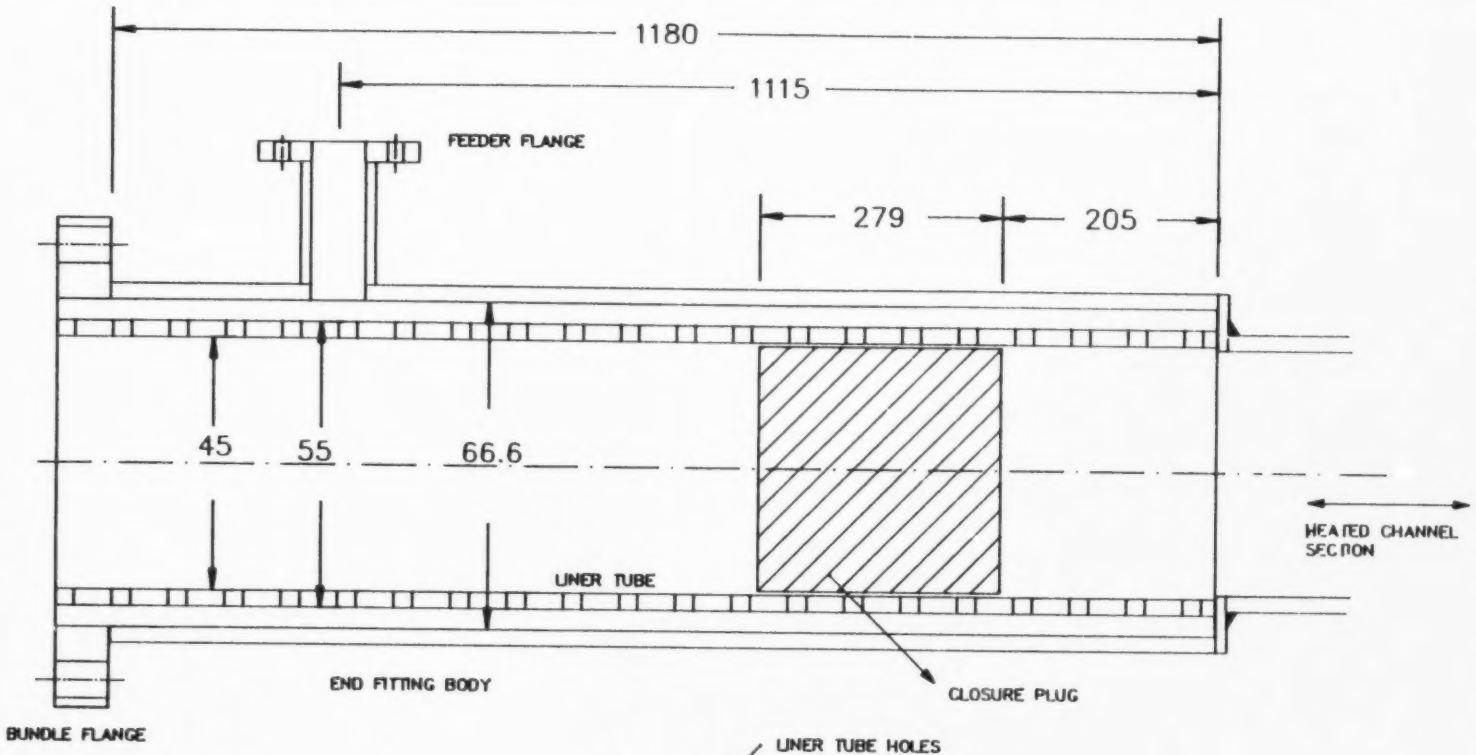


3 HEATER ELEMENTS IN EVERY BUNDLE
HAVE EMBEDDED WALL SHEATH THERMOCOUPLES.

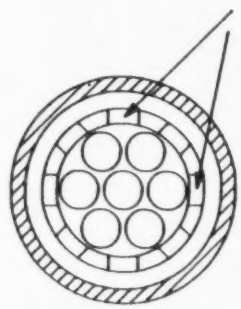
AECB THERMOSYPHONING FACILITY		
ELEMENT	DESIGN	Idea Research
	FIGURE 26	



AECB THERMOSYPHONING FACILITY		
CHANNEL	DESIGN	IDEA Research
	FIGURE 27	



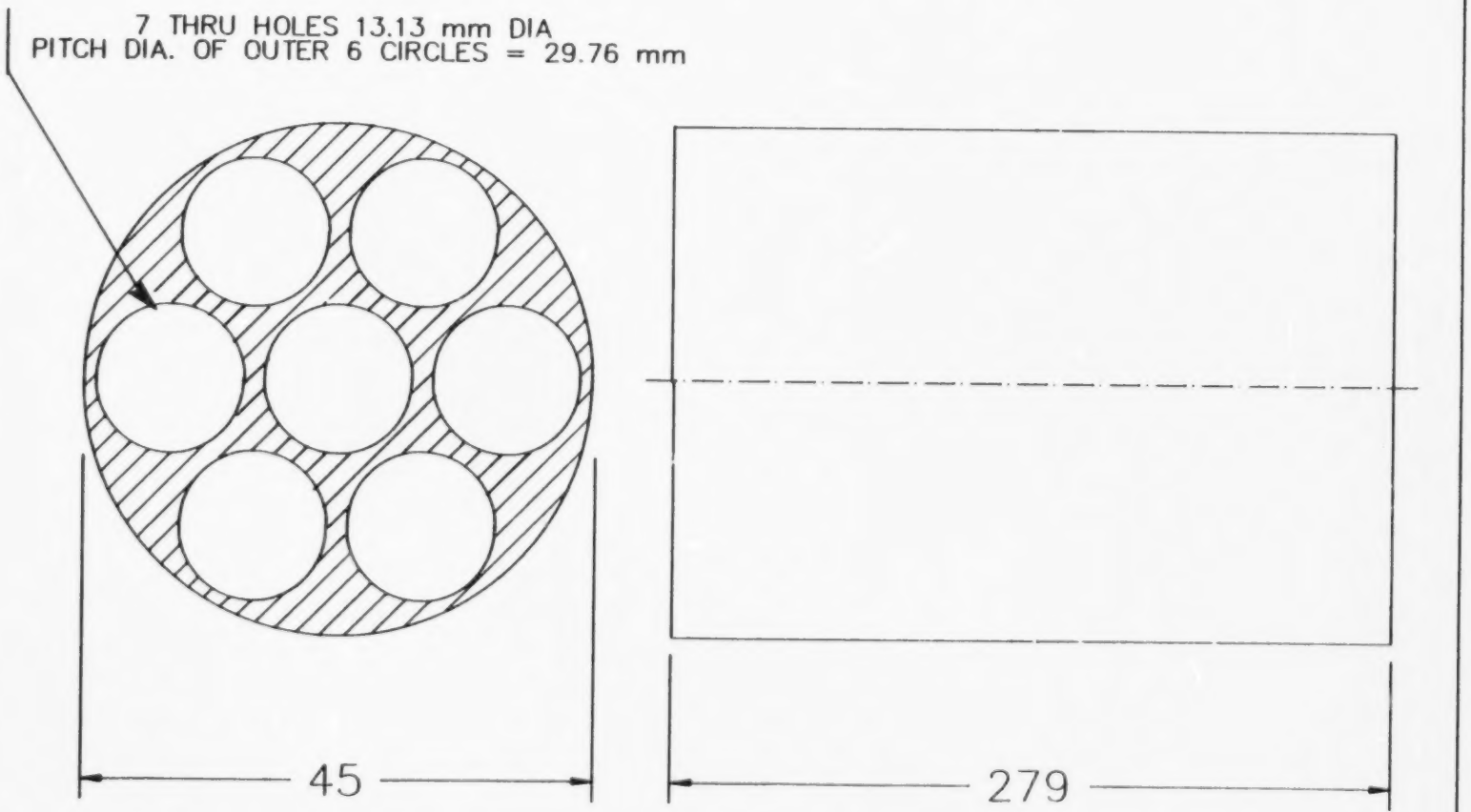
CHANNEL SECTION



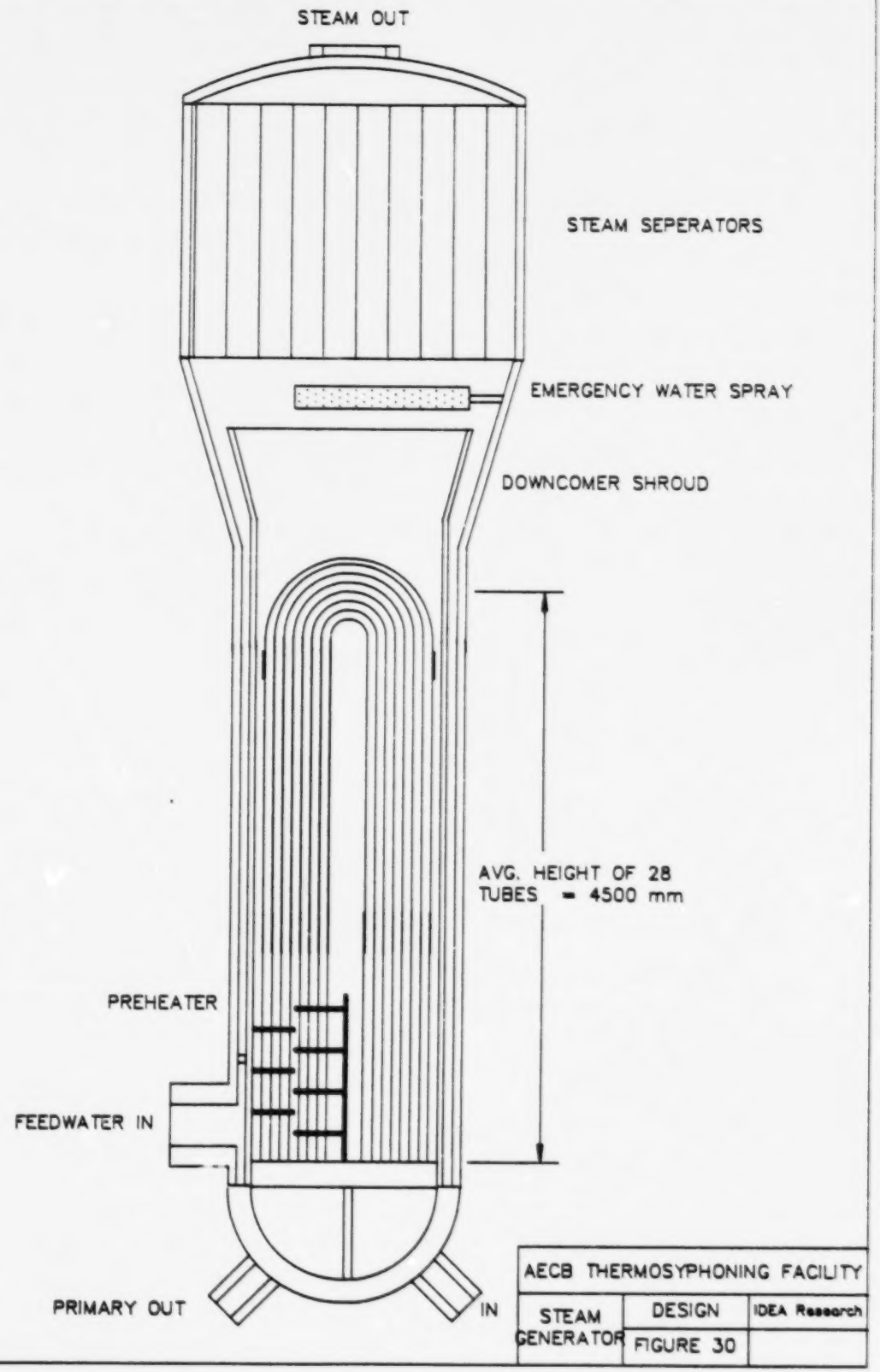
END FITTING SECTION

NOT TO SCALE

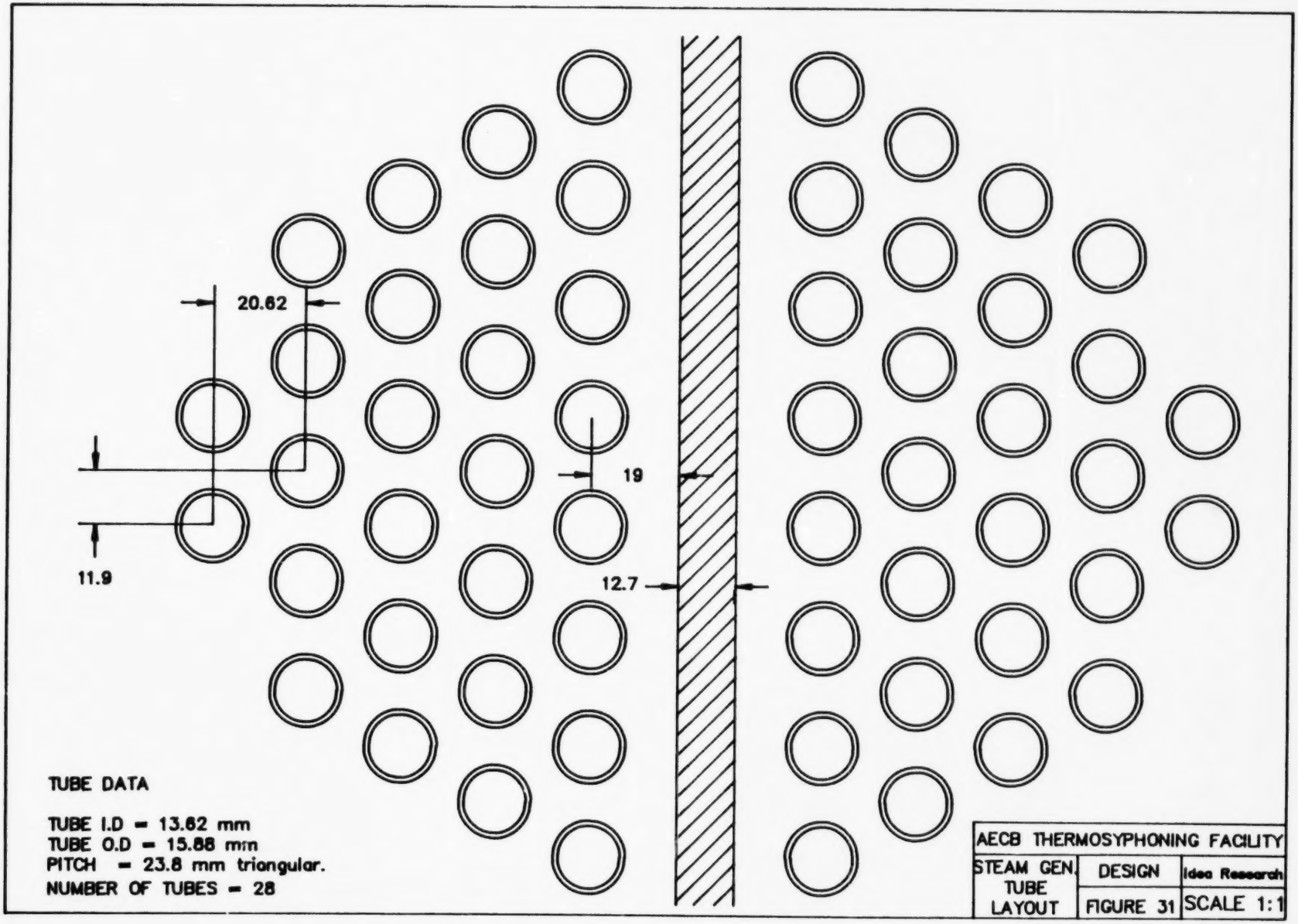
AECB THERMOSYPHONING FACILITY		
END FITTING	DESIGN	IDEA Research
	FIGURE 28	



AECB THERMOSYPHONING FACILITY		
SHIELD PLUG	DESIGN	Idea Research
	FIGURE 29	



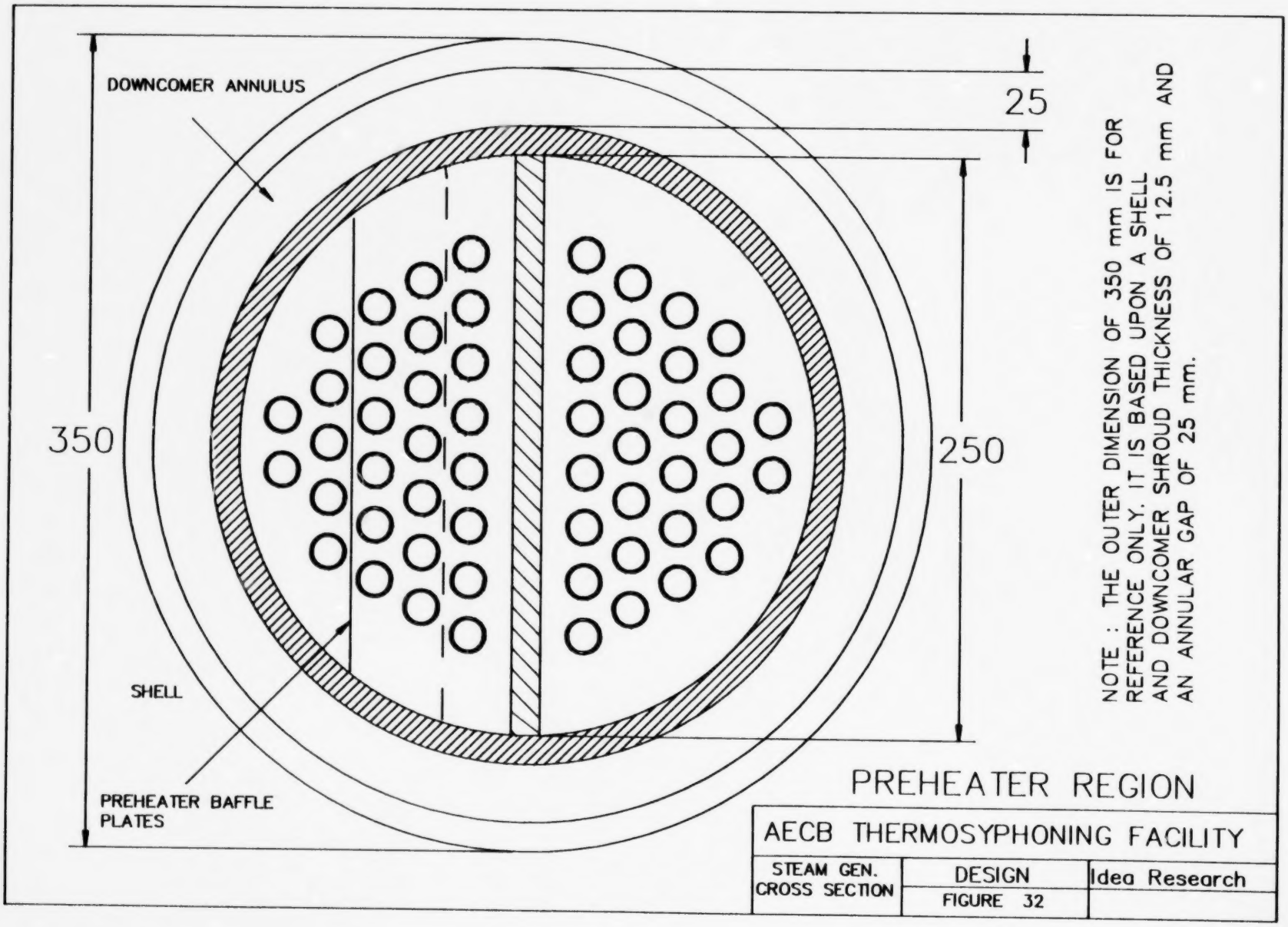
AECB THERMOSYPHONING FACILITY		
STEAM GENERATOR	DESIGN	IDEA Research
	FIGURE 30	

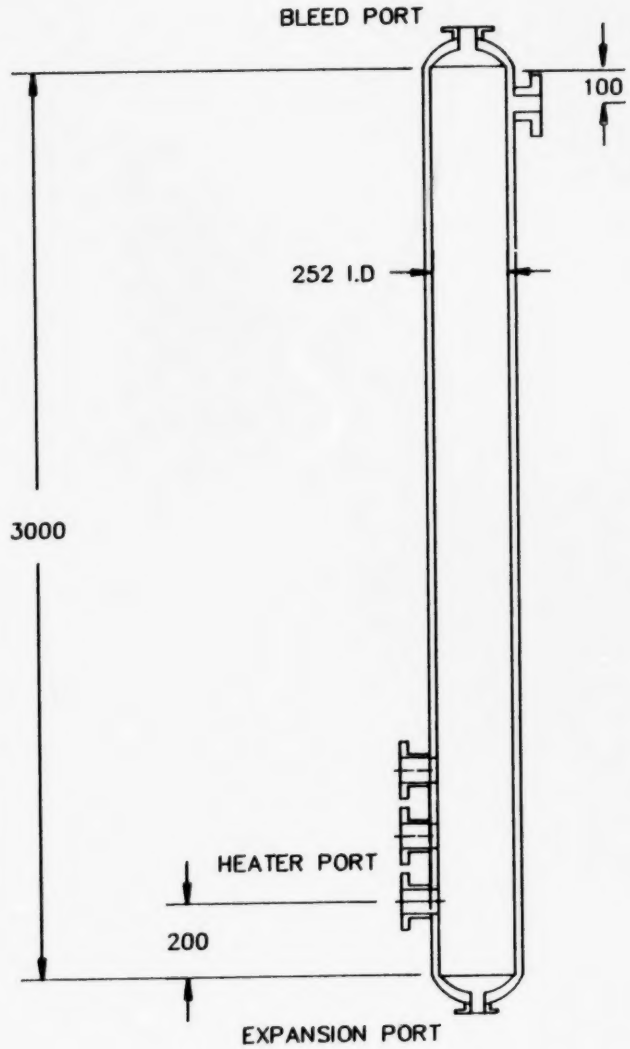


TUBE DATA

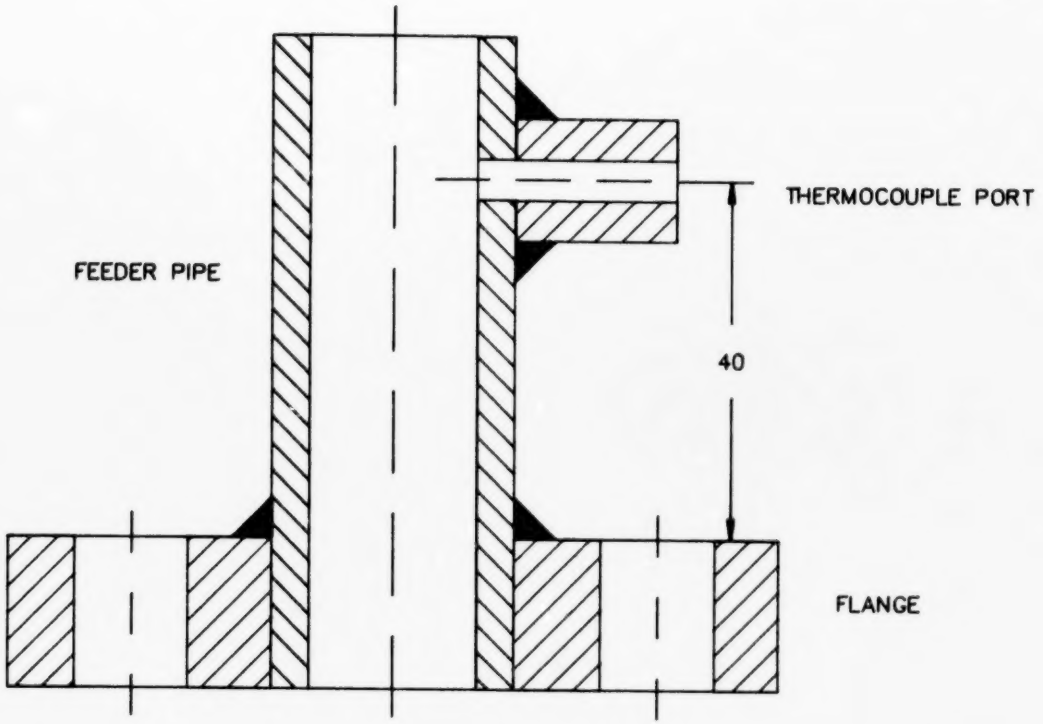
TUBE I.D = 13.62 mm
TUBE O.D = 15.88 mm
PITCH = 23.8 mm triangular.
NUMBER OF TUBES = 28

AECB THERMOSYPHONING FACILITY		
STEAM GEN. TUBE LAYOUT	DESIGN	Idea Research
	FIGURE 31	SCALE 1:1


DOWNCOMER ANNULUS
25
350
250
SHELL
PREHEATER BAFFLE PLATES
NOTE : THE OUTER DIMENSION OF 350 mm IS FOR REFERENCE ONLY. IT IS BASED UPON A SHELL AND DOWNCOMER SHROUD THICKNESS OF 12.5 mm AND AN ANNULAR GAP OF 25 mm.
PREHEATER REGION
AECB THERMOSYPHONING FACILITY
STEAM GEN. CROSS SECTION
DESIGN
FIGURE 32
Idea Research



AECB THERMOSYPHONING FACILITY		
PRESSURIZER	DESIGN	IDEA Research
	FIGURE 33	



AECB THERMOSYPHONING FACILITY

FEEDER END	DESIGN	IDEA Research
	FIGURE 34	

SECTION 6

- TEST MATRIX -

A. INTRODUCTION

The test matrix is divided into two distinctly different sections. The main objective of the first part of the test matrix is to ascertain that the individual components are manufactured and assembled per design and operational requirements and that the system as a whole meets the same rigorous requirements. This part is termed "Commissioning Tests" and includes tests of the safety systems, instrumentation and data acquisition systems and control systems. The second part consists of the identification of independent variables and boundary conditions for various tests and the description of the tests specification.

B. OBJECTIVES

The objectives of the facility have been identified previously and include the following :

i) identification of flow regimes and their transition.

ii) identification of the effect of non condensibles.

iii) examination of system instabilities.

iv) caracterisation of steam generator heat removal capabilities and limitations.

v) identification of channel to channel interactions.

vi) effect of subsystems behaviour.

C. COMMISSIONING TESTS

The purpose of the commissioning tests is to calibrate and verify the expected behaviour of the loop. They include the following :

i) component testing.

ii) loop testing.

iii) safety systems testing.

iv) instrumentation testing and calibration.

v) data acquisition and display system testing.

vii) control system calibration.

viii) heat balances.

ix) heat loss evaluation.

1. Component Testing

Some of the components will be tested by the manufacturer and the performance curve will be provided to insure that the design requirements are met. Those components are :

i) Pumps (primary and auxiliary)

ii) Steam generators and heat exchangers or condensers.

iii) Channel assemblies.

iv) Valves.

v) Pressuriser.

vi) Headers.

2. Loop Testing

Once assembled the loop will be tested for pressure integrity at various pressure and temperature levels up to the specified design limits.

3. Safety Systems Testing

The testing of the safety systems include the calibration of the pressure relief valves and the calibration of the overtemperature protection thermocouples in the channels and in the pressuriser.

4. Heat Loss Evaluation

Prior to the tests a heat loss evaluation must be performed for different primary side conditions in order to evaluate the efficiency of the facility's isolation. A criterion for satisfactory heat losses can be that 75% of the heat generated in the core is transfered to the steam generators.

D. INDEPENDENT VARIABLES

The identification of independent variables is the first task in the preparation of a test matrix. Subsequently the range of variation of these variables must also be specified based upon the anticipated range of their change in the reactor. The total number of test points for a given variable will also be based on expected dispersion.

The choice of range and the number of discrete points within a given range for all independent variables is a subjective decision that can be reevaluated during testing.

The independent variables that have been identified are as follows :

i) Total core power.

ii) Channel power distribution.

iii) Secondary Side Conditions.

iv) Inventory.

v) Pump rundown.

vi) Pump trip time.

viii) Non condensibles.

ix) Number of pumps per loop.

x) Shutdown cooling system.

xi) Location and size of break.

1. Total Core Power

The total core power will simulate the core power that is expected for a given scenario. In general the core power will be established at 10% as a pre-transient value, then run down sharply to 4% power and linearly decreased to 2% power in 2 hours.

2. Channel Power Distribution

The scaling of the channels imposes a maximum power to each of them when the facility is operating at its full scaled power.

According to the scaling of the facility, a 2056 MW core translates into a 7.491 MW full power scaled facility. The maximum channel power in the Candu is 6.5 MW. Therefore the maximum scaled power per channel will be :

(7.491/10) / (2056/380) * 6.5 = 900 kW

This power corresponds to a scaled flow of 3.29 kg/s in channels A-3 and B-3.

The maximum channel power that can be applied to each individual channel is listed below :

Maximum power for channel A-1 : 520 kW

Maximum power for channel A-2 : 472 kW

Maximum power for channel A-3 : 900 kW

Maximum power for channel A-4 : 472 kW

Maximum power for channel A-5 : 612 kW

Maximum power for channel B-1 : 520 kW

Maximum power for channel B-2 : 472 kW

Maximum power for channel B-3 : 900 kW

Maximum power for channel B-4 : 472 kW

Maximum power for channel B-5 : 612 kW

The maximum scaled power of the facility at 100% power is 5.95 MW. The maximum power that can be applied to a channel during thermosyphoning or low power operation is the product of the above maximum channel powers by the fraction of full power.

During thermosyphoning, the highest reactor power that can be expected is 4% of its full power. At 4% scaled power level the channel powers would be 4% of the above maximum powers. Let us normalise these channel powers to unity. In order to isolate the effect of channel power and relative channel power the following set of experiments is proposed :

Channel number	Case number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
A-1	1.	.75	.5	1.	X	X	X	1.	X	1.	X	1.	1.
A-2	1.	.75	.5	X	1.	X	X	1.	X	1.	1.	X	1.
A-3	1.	.75	.5	X	X	1.	X	X	1.	1.	1.	1.	X
A-4	1.	.75	.5	X	X	X	X	X	1.	1.	1.	1.	1.
A-5	1.	.75	1.	X	X	X	1.	X	X	X	1.	1.	1.
B-1	1.	.75	.5	1.	X	X	X	1.	X	1.	X	1.	1.
B-2	1.	.75	.5	X	1.	X	X	1.	X	1.	1.	X	1.
B-3	1.	.75	.5	X	X	1.	X	X	1.	1.	1.	1.	X
B-4	1.	.75	.5	X	X	X	X	X	1.	1.	1.	1.	1.
B-5	1.	.75	1.	X	X	X	1.	X	X	X	1.	1.	1.

X is a fraction which will be determined by cases 1, 2 and 3 such as .5 < X < 1.

3. Secondary Side Conditions

Witnout a break in the system the secondary side is the potential heat sink for the power generated in the core. In the Candu the secondary side can be depressurised slowly through the normal, power level adjusted feedwater flow, or very rapidly throuyh an automatic or manual crash cooldown. Those two modes provide two different heat sinks for the primary side. Therefore the secondary side will either be at a temperature around 220 °C or at a temperature of 100 °C.

4. Inventory

With no breaks in the system the facility can either be run with no make-up water (feed pump inoperative) or the feed pumps can provide enough make up water to keep the primary side always in one phase liquid.

5. Pump Rundown

The pumps will be driven by variable speed electrical motors. Since it is almost impossible to reproduce the pump rundown of a Candu 600, the actual pump rundown becomes a test matrix parameter. The pump rundown will be set in such a way as to be able to control the temperature gradient between inlet and outlet feeders. Four pump rundown will be used such as to achieve a temperature difference of 0, 5, 10 and 20 °C between the inlet and outlet feeder of the highest power channel.

6. Pump Trip Time

The pump trip time will be accident scenario dependent. For each scenario two trip times will be used. The first one will be as specified in the safety report, the second one will be design centered (credit of the first signal).

7. Non Condensibles

The non condensibles should be located at the top of the steam generator tubes. Two volumes of non consensibles will be injected into the facility. One that would fill the bends of the steam generator tubes and the second one that would fill the entire tube volume.

8. Number of Pumps per Loop

The Candu is designed to operate with one pump per loop operating. In that case the initial enthalpy distribution is assymetrical in the loop and the enthalpy rise across the core is about 60% of the full power two pumps operating value. Some of the above scenario will be repeated with one primary pump running before the beginning of the thermosypnoning transient.

9. Shutdown Cooling System

The shutdown cooling system can be operated with either the primary pumps or the shutdown cooling pumps operating. Both cases will be investigated during a thermosyphoning scenario.

10. Location and Size of Break

Two major break locations have been identified (inlet and outlet header). The break is designed to simulate a small break only. Nevertheless two break sizes will be investigated. The first one similar to a leak providing very small depressurisation with long delayed ECI injection, the second one will be representative of a true feeder break.

E. TEST MATRIX

The base case for the experiments is defined as follows starting with the identification of a base case.

Base Case (BC) conditions :
i) power distribution as in case 1 of D.2 above.
ii) normal feedwater.
iii) normal feed and bleed.
iv) normal pump rundown.
v) pump tripped at start of transient.
vi) no addition of non-condensibles.
vii) 2 pumps per loop.
viii) no SDCS.
ix) no break.

Total number of experiments : 1

1. Effect of Channel Power Distribution

i) power distribution as in cases 2 to 13 of D.2 above.
BC for items ii) to ix).

Total number of experiments : 12

2. Effect of Secondary Side Conditions

i) power distribution as in cases 1 to 13 of D.2 above.
ii.1) steam generator crash cooldown.
ii.2) steam generator rapid cooldown (increased feedwater flow).
BC for items iii) to ix).

Total number of experiments : 26

3. Effect of Inventory

iii.1) no primary feedwater, bleed closed.
iii.2) no primary feedwater, bleed open.
BC for i), ii), iv) to ix)

Total number of experiments : 2

4. Effect of Pump Rundown

i) power distribution as in cases 1 to 5 of D.2 above.
iv) three different pump rundown as defined in D.5.
BC for ii), iii), v) to ix.

Total number of experiments : 15

5. Effect of Pump Trip Timing

i) power distribution as in cases 1 to 13 of D.2 above.
v) pump trip delayed by 20s.
BC for ii) to iv), vi) to ix)

Total number of experiments : 13

6. Effect of Non Condensibles

vi) two volumes of non condensibles as defined in D.7.
BC for i) to v), vii) to ix)

Total number of experiments : 2

7. Effect of One Pump per Loop

i) power distribution as in cases 1 to 5 of D.2 above.
vii) one pump per loop.
BC for ii) to vi), viii) to ix).

Total number of experiments : 5

8. Effect of the Shutdown Cooling System

Base Case
a. Actuation of the SDCS 30 mn after the beginning of the transient.
b. SDCS cooling mode. Loss of primary pumps.
c. SDCS cooling mode. Loss of SDCS pumps.

Total number of experiments : 3

9. Effect of a Small Break

Base Case with one very small break.
a. pumps lost at begining of transient
b. pumps lost 10 mn into transient.
Same experiments with a feeder size break.

Both sets of experiments for inlet and outlet header breaks.

Total number of experiments : 8

10. Other Experiments

a. Simulation of a main steam line break witn empty steam generator.

b. Simulation of EWS injection with both steam generators empty.

Total number of experiments : 2

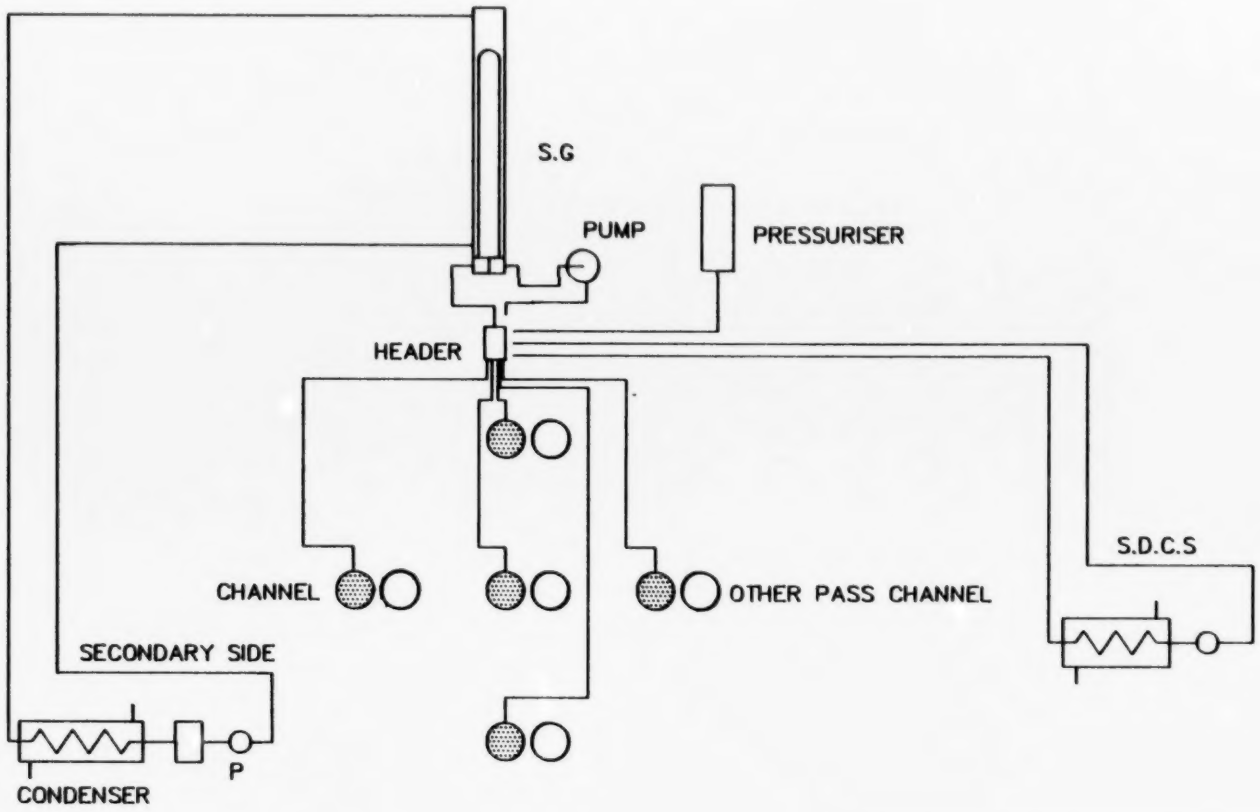
SECTION 7

- FACILITY LAYOUT -

INTRODUCTION

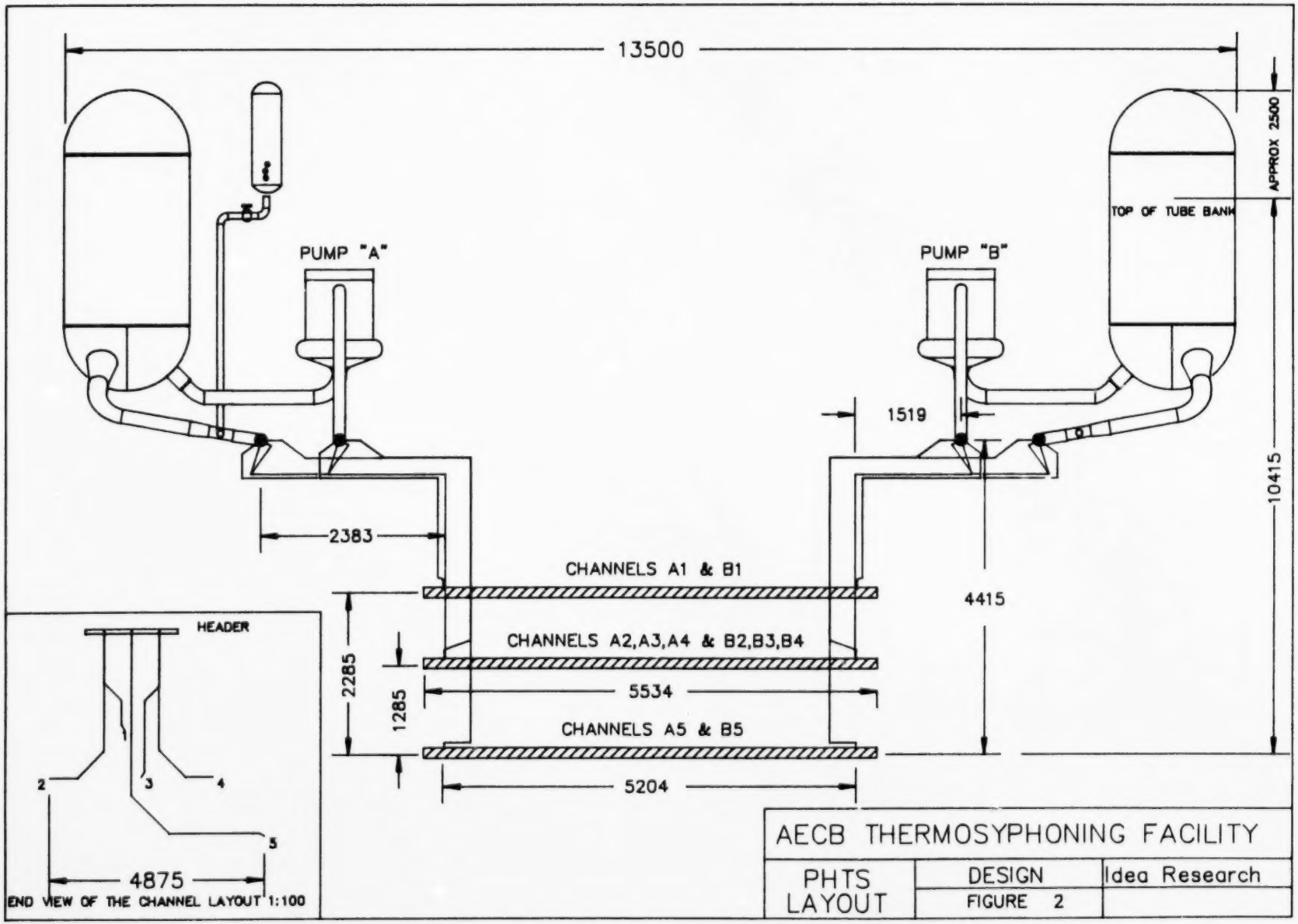
The spatial layout of the primary heat transport system components is defined by the conceptual design and is a direct consequence of the scaling methodology. Therefore the PHTS must be built without significant distorsions. If any distorsion has to be introduced its effect on the scaling must be assessed beforehand. The layout of the auxiliary systems is location dependent and can take any suitable form. The auxiliary systems must only meet the performance criteria imposed on them.

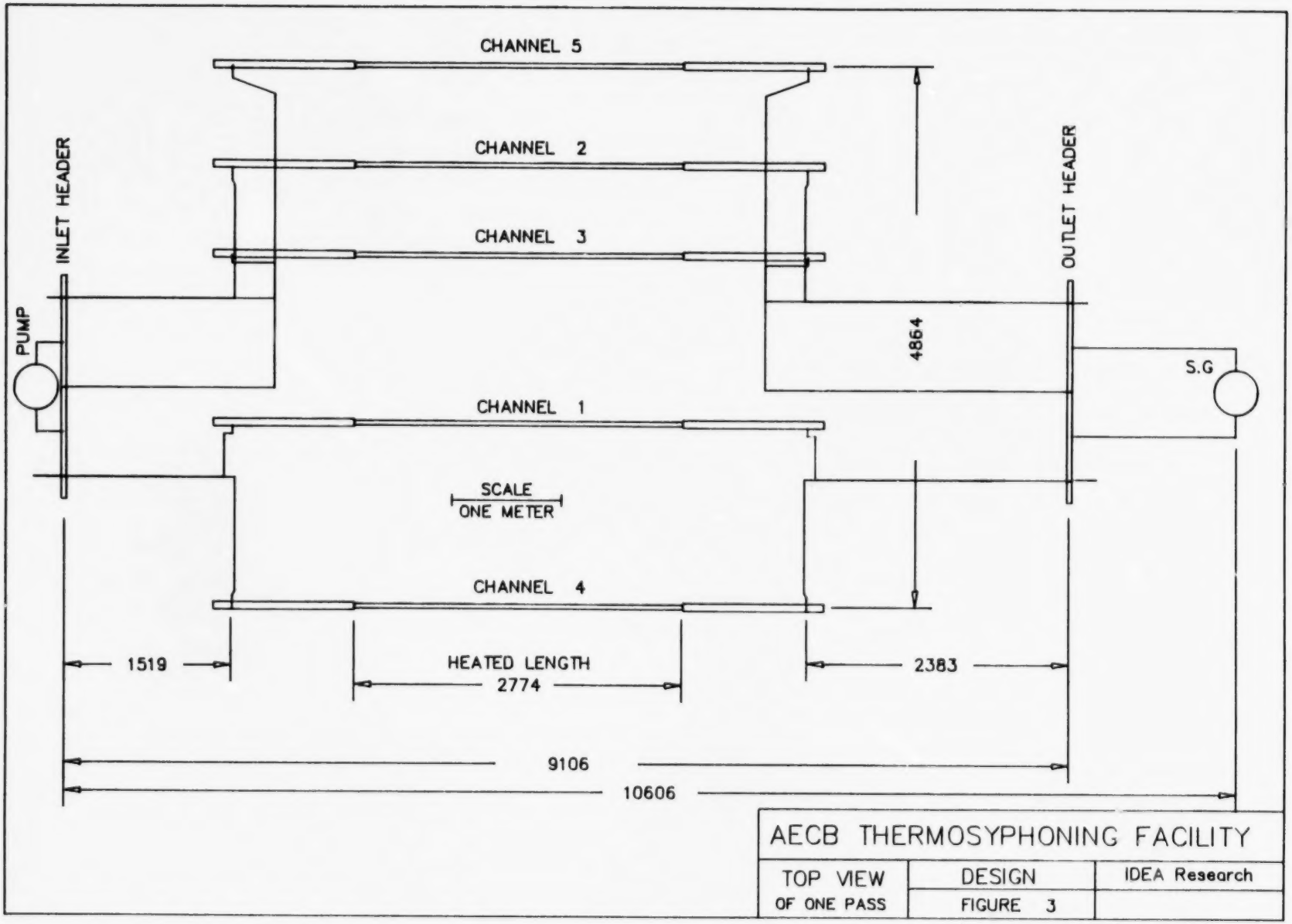
Figure 1 presents schematically the concept of parallel passes in the figure of eight loop of the facility. In the Candu 600 the corresponding channels of two passes are placed parallel to each other to flatten the neutron flux. In the thermosyphoning facility that configuration is maintained only to preserve the pipe length scaling. Figures 2 through 5 show the schematic layout of the PHTS. It is shown that the PHTS would occupy a space 14 metres high, 14 metres long and 5 metres wide. The condenser, feedwater system, auxiliary systems and the storage tanks will occupy a floor space similar in size. A control and computer room, physically separated from the test facility is also required. Figure 6 shows a block diagram of the facility.

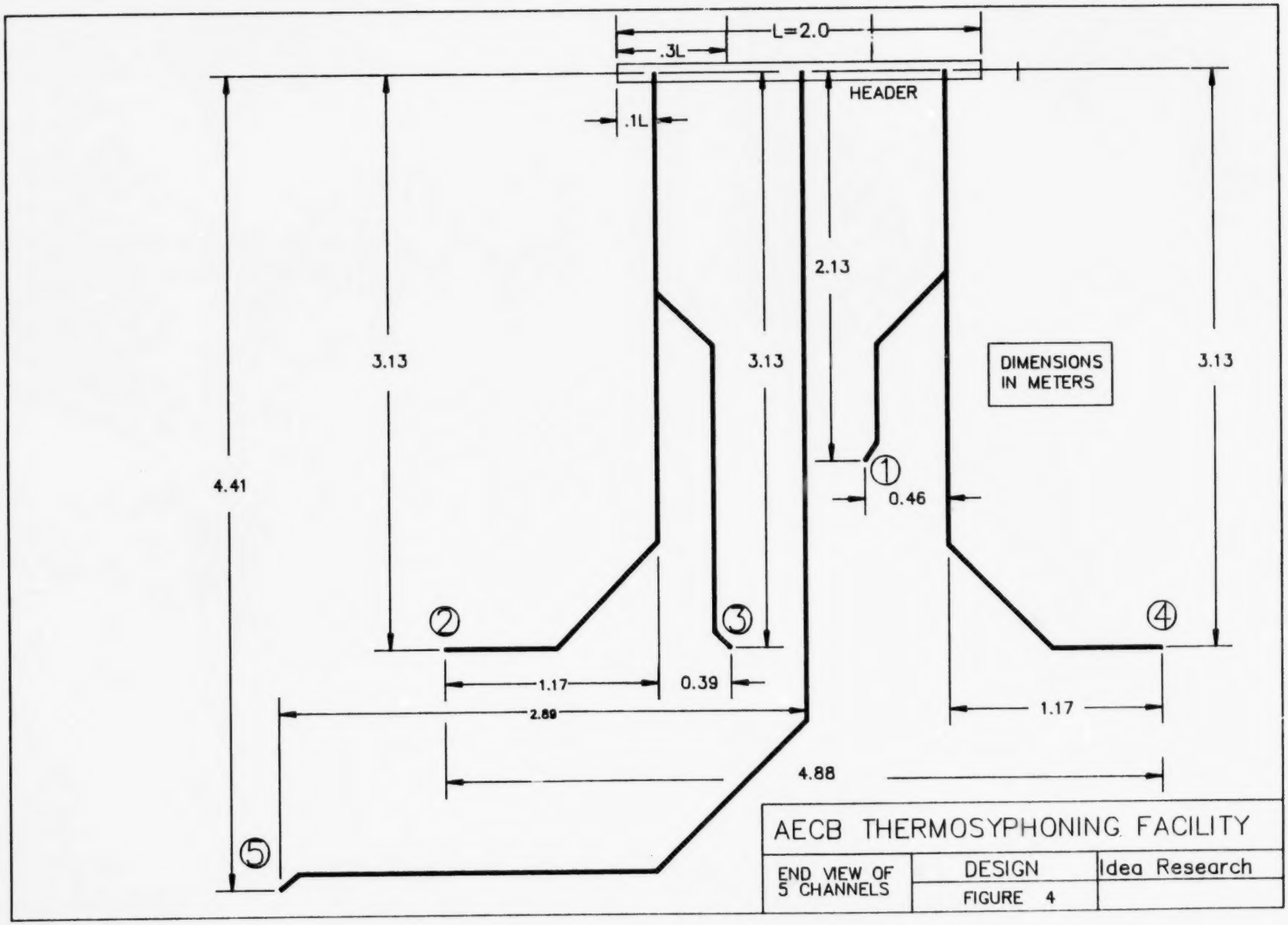


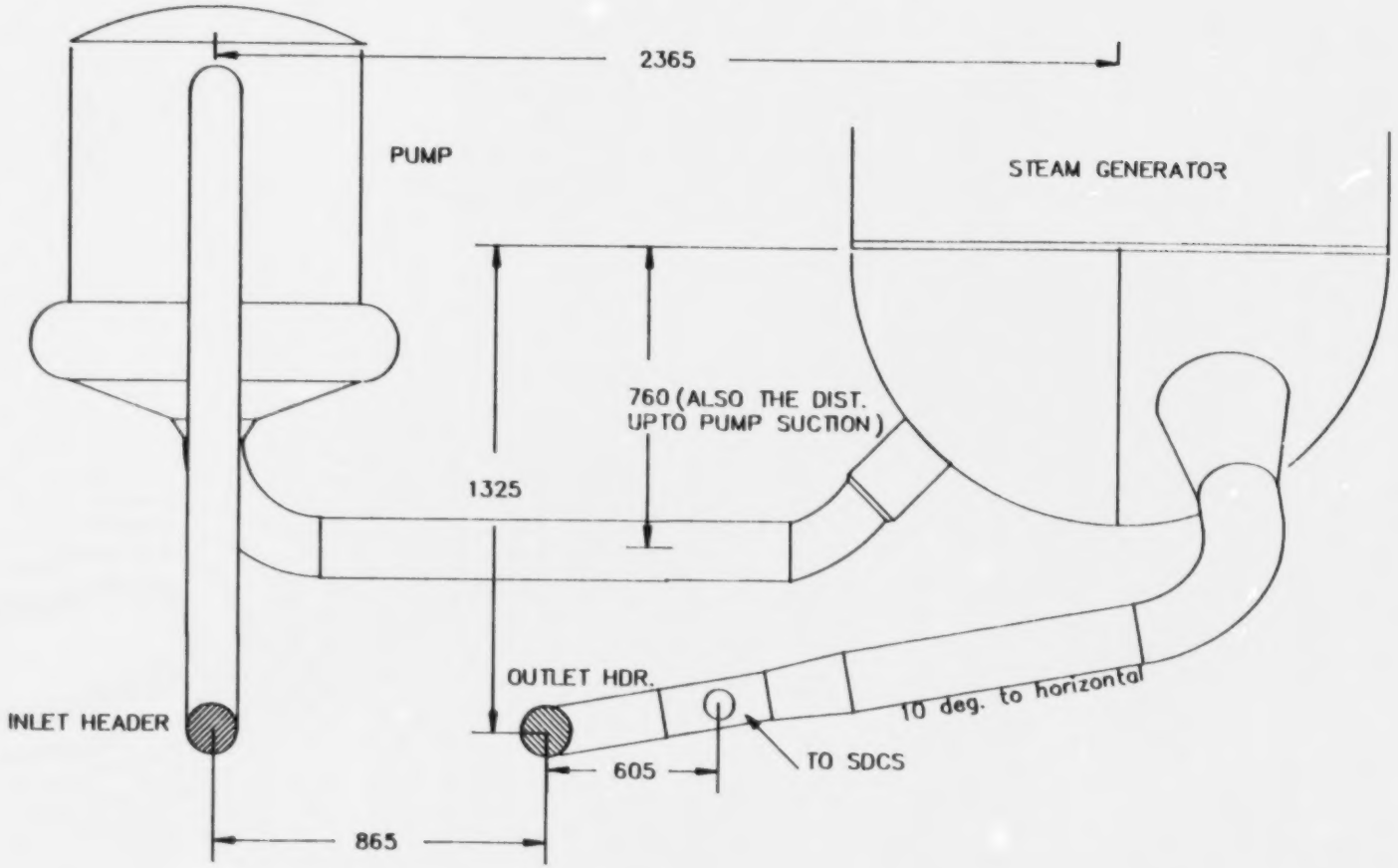
AECB THERMOSYPHONING FACILITY

PARALLEL CHANNELS	DESIGN	IDEA Research
	FIGURE 1	

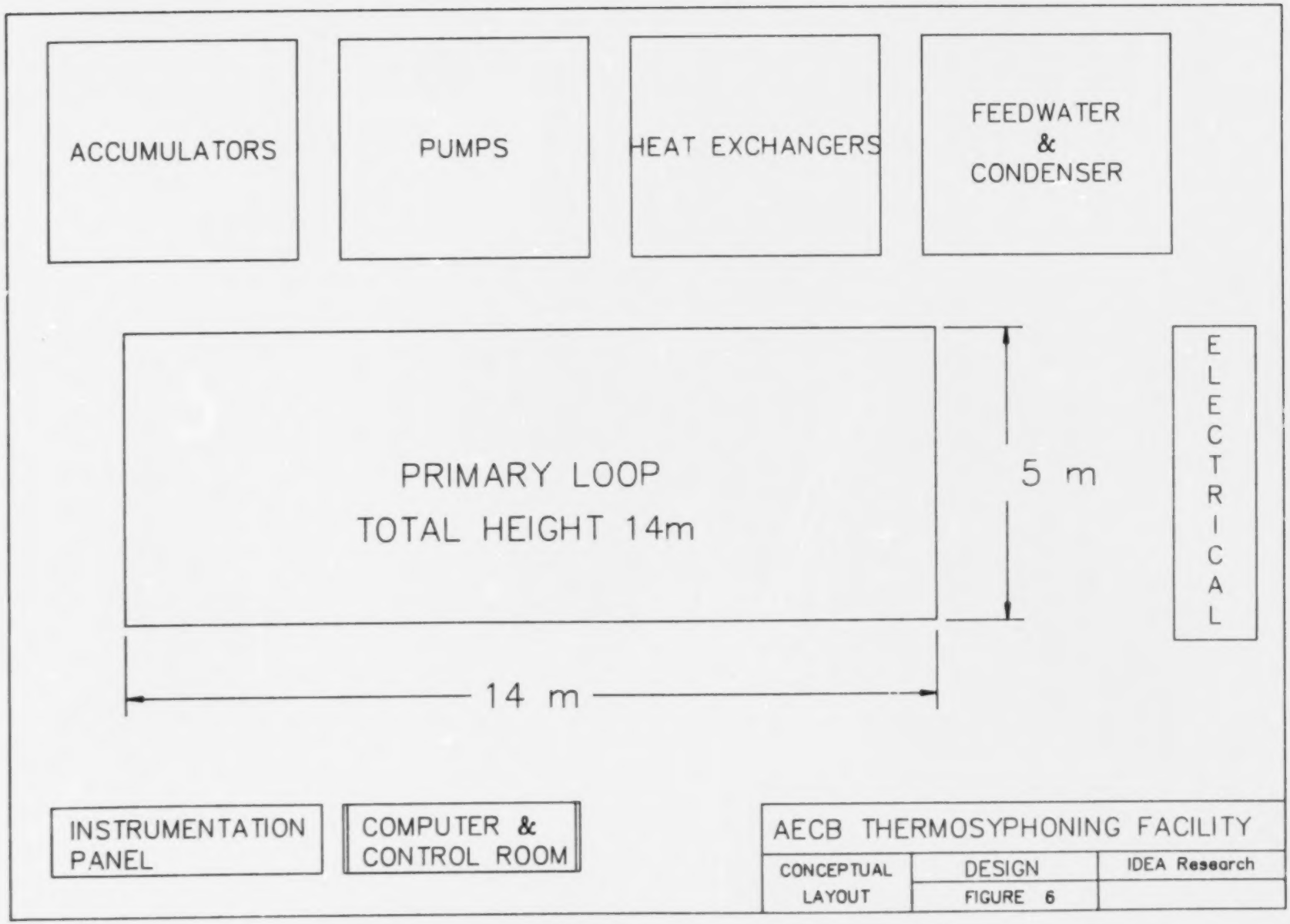

13500
APPROX 2500
TOP OF TUBE BANK
PUMP "A"
PUMP "B"
1519
10415
2383
CHANNELS A1 & B1
4415
CHANNELS A2,A3,A4 & B2,B3,B4
2285
1285
5534
CHANNELS A5 & B5
5204
HEADER
2
3
4
5
4875
END VIEW OF THE CHANNEL LAYOUT 1:100
AECB THERMOSYPHONING FACILITY
PHTS LAYOUT
DESIGN
FIGURE 2
Idea Research


CHANNEL 5
CHANNEL 2
CHANNEL 3
CHANNEL 1
CHANNEL 4
INLET HEADER
OUTLET HEADER
PUMP
S.G
4864
SCALE
ONE METER
1519
HEATED LENGTH
2774
2383
9106
10606
AECB THERMOSYPHONING FACILITY
TOP VIEW
OF ONE PASS
DESIGN
FIGURE 3
IDEA Research


L=2.0
.3L
HEADER
.1L
2.13
3.13
3.13
3.13
DIMENSIONS
IN METERS
4.41
①
0.46
②
③
④
1.17
0.39
1.17
2.89
4.88
⑤
AECB THERMOSYPHONING FACILITY
END VIEW OF
5 CHANNELS
DESIGN
FIGURE 4
Idea Research



AECB THERMOSYPHONING FACILITY		
PUMP & S.G LAYOUT	DESIGN	IDEA Research
	FIGURE 5	


ACCUMULATORS
PUMPS
HEAT EXCHANGERS
FEEDWATER & CONDENSER
PRIMARY LOOP
TOTAL HEIGHT 14m
5 m
ELECTRICAL
14 m
INSTRUMENTATION PANEL
COMPUTER & CONTROL ROOM
AECB THERMOSYPHONING FACILITY
CONCEPTUAL LAYOUT
DESIGN
FIGURE 6
IDEA Research

APPENDIX - S2

```
10 'PROGRAM TO OBTAIN SCALING DATA FOR THE THERMOSYPHONING
20 'FACILITY USING TWO PHASE SCALING LAWS OF ISHII
30 OPEN "O",#1,"B:sc.dat"
40 N1=7
50 NCO=95:NC1=5
60 DD1=13.12
70 LR=.5
80 DO=103.4
90 DDO=13.12
100 AVCHPO=6000
110 LCOREO=12*495.3
120 LEFOO=25.4*12*7.3183
130 PI=3.1415927#
140 NO=37
150 TAO=PI/4*DO^2
160 FAO=TAO-NO*PI/4*DDO^2
170 FPPO=FAO/NO
180 DHO=(DO^2-NO*DDO^2)/(DO+NO*DDO)
190 PRINT ""
200 UR=LR^.5
210 QR=LR^(-.5)
220 DR=LR^(.25)
230 DH1=DR*DHO
240 D1=(DH1+SQR(DH1^2+4*(DH1*N1*DD1+N1*DD1^2)))/2
250 FA1=PI/4*(D1^2-N1*DD1^2)
260 FPP1=FA1/N1
270 TA1=PI/4*(D1^2)
280 AR=FA1/FAO
290 VR=AR*LR
300 QTR=VR*QR
310 AFR=FA1/FAO
320 AFRR=AFR*NC1/NCO
330 TR=SQR(LR)
340 ATR=TA1/TAO
350 QTR1=QTR*AVCHPO
360 LHEATER1=LCOREO*LR
370 LEFOO=25.4*12*7.3183
380 LEFO1=LEFOO*LR
390 PRINT #1,"LENGTH RATIO =",LR
400 PRINT #1,"VELOCITY RATIO =",UR
410 PRINT #1,"HEAT DENSITY RATIO =",QR
420 PRINT #1,"HYDRAULIC DIA. RATIO =",DR
430 PRINT #1,"VOLUME RATIO =",VR
440 PRINT #1,"TOTAL HEAT RATIO =",QTR
450 PRINT #1,"FLOW AREA RATIO =",AFR
460 PRINT #1,"CHANNEL AREA RATIO =",ATR
470 PRINT#1,""
480 PRINT #1,"TIME RATIO =",TR
490 PRINT #1,""
500 PRINT #1,TAB(31),"FACILITY","CANDU"
510 PRINT #1,""
520 PRINT #1,"TEST SECTION & CORE"
530 PRINT #1,"NUMBER OF CHANNELS PER PASS",TAB(30),NC1,NCO
540 PRINT #1,"TEST SECTION TUBE I.D",TAB(30),D1,DO
550 PRINT #1,"HEATED TEST SECTION LENGTH",TAB(30),LHEATER1,LCOREO
```

```
560 PRINT #1,"HEATER ROD O.D",TAB(30),DD1,DDO
570 PRINT #1,"NUMBER OF HEATER RODS",TAB(30),N1,NO
580 PRINT #1,"CROSS SECTION OF T.S TUBE",TAB(30),TA1,TAO
590 PRINT #1,"FLOW AREA IN T.S TUBE",TAB(30),FA1,FAO
600 PRINT #1,"FLOW AREA PER HEATER ROD",TAB(30),FPP1,FPPO
610 PRINT #1,"T.S HYDRAULIC DIA.",TAB(30),DH1,DHO
620 PRINT #1,"T.S. TOTAL POWER",TAB(30),QTR1,AVCHPO
630 PRINT #1,""
640 PRINT #1,"END FITTINGS"
650 LEFO=25.4*12*7.3183
660 LEF1=LEFO*LR
670 PRINT #1,"LENGTH",TAB(30),LEF1;LEFO
680 PRINT #1,""
690 PRINT #1,"OUTLET HEADER"
700 LOHO=6458!
710 AVLOHO=LOHO/8
720 AVLOH1=AVLOHO*LR
730 LOH1=AVLOH1*5
740 DOHO=406
750 'FLOW AREA PER FEEDER IN THE HEADER
760 FFH=PI*DOHO^2/4*4/95
770 'EQ. DIA FOR THIS UNIT FLOW AREA
780 AOHO=DOHO^2*PI/4
790 EFA=4/PI*SQR(FFH)
800 'SCALED DIA.
810 EFA1=LR^.25*EFA
820 DOH1=SQR(2)*EFA1
830 AOH1=DOH1^2*PI/4
840 PRINT #1,  "LENGTH",TAB(30),LOH1,LOHO
850 PRINT #1,"CROSS SECTION AREA",TAB(30),AOH1,AOHO
860 PRINT #1,"I.D",TAB(30),DOH1,DOHO
870 PRINT #1,""
880 PRINT #1,"STEAM GENERATOR"
890 NSGTO=3550
900 NSGT1=NSGTO*NC1/NCO*AFR
910 NSGT1=INT(NSGT1+.5)
920 DSGTIO=15.88-2*1.13
930 DSGTI1=DSGTIO
940 DSGTOO=15.88
950 DSGTO1=DSGTOO
960 ASGTO=DSGTOO^2*PI/4
970 ASGT1=ASGTO
980 LAVSGTO=6.6603E+07/NSGTO
990 LAVSGT1=LAVSGTO*LR
1000 HSGTO=LAVSGTO/2
1010 HSGT1=HSGTO*LR
1020 PRINT #1,"NUMBER OF TUBES",TAB(30),NSGT1,NSGTO
1030 PRINT #1,"TUBE ID",TAB(30),DSGTI1,DSGTIO
1040 PRINT #1,"TUBE O.D",TAB(30),DSGTO1,DSGTOO
1050 PRINT #1,"CROSS SECTION OF EACH TUBE",TAB(30),ASGT1,ASGTO
1060 PRINT #1,"LENGTH OF AVERAGE TUBE",TAB(30),LAVSGT1,LAVSGTO
1070 PRINT #1,"HEIGHT OF AVERAGE TUBE",TAB(30),HSGT1,HSGTO
1080 PRINT #1,""
1090 PRINT #1,"INLET HEADER"
1100 LIHO=6407
```

```
1110 'AVERAGING THE FLOW PATH LENGTHS INSIDE THE HEADER
1120 AVLIHO=LIHO/8
1130 AVLIH1=AVLIHO*LR
1140 LIH1=AVLIH1*5
1150 DIHO=370
1160 FFH=PI*DIHO^2/4*4/95
1170 EFA=4/PI*SQR(FFH)
1180 EFA1=LR^.25*EFA
1190 DIH1=SQR(2)*EFA1
1200 AIHO=DIHO^2*PI/4
1210 AIH1=DIH1^2*PI/4
1220 PRINT #1,"LENGTH",TAB(30),LIH1,LIHO
1230 PRINT #1,"CROSS SECTION",TAB(30),AIH1,AIHO
1240 PRINT #1,"I.D",TAB(30),DIH1,DIHO
1250 PRINT #1,""
1260 'INLET FEEDERS
1270 PRINT #1,""
1280 PRINT #1,"INLET FEEDERS"
1290 PRINT #1,""
1300 PRINT #1,"LENGTHS ARE NOT SCALED FROM ANY PARTICULAR FEEDERS"
1310 PRINT #1,"FEEDERS C-9,Q-2,K-9,Q-2 AND T-11 ARE USED TO OBTAIN"
1320 PRINT #1,"REPRESENTAIVE FEEDER GEOMETRIC INFORMATION"
1330 COUNTER=1
1340 WHILE COUNTER<=10
1350 READ F$,N1,N2,D1,D2
1360 X=0:Y=0:Z=0:L=0
1370 FOR I=1 TO N1
1380 READ XL,YL,ZL,LL
1390 X=X+XL:Y=Y+YL:Z=Z+ZL:L=L+LL
1400 NEXT I
1410 L1=L
1420 IF N2=0 THEN 1490
1430 FOR J=1 TO N2
1440 READ XL,YL,ZL,LL
1450 X=X+XL:Y=Y+YL:Z=Z+ZL:L=L+LL
1460 NEXT J
1470 L2=L-L1
1480 GOTO 1500
1490 L2=0
1500 D1=D1*25.4
1510 D2=D2*25.4
1520 X=X*25.4
1530 Y=Y*25.4
1540 Z=Z*25.4
1550 L=L*25.4
1560 L1=L1*25.4
1570 L2=L2*25.4
1580 'SCALED FEEDER DIA AND LENGTH COORDINATES
1590 FDRDO1=D1
1600 FDRD11=FDRDO1*(LR*AFR^2)^.2
1610 FDRDO2=D2
1620 FDRD21=FDRDO2*(LR*AR^2)^.2
1630 FDRX1=X*LR
1640 FDRY1=Y*LR
1650 FDRZ1=Z*LR
```

```
1660 FDRL1=L*LR
1670 FDRL11=L1*LR
1680 FDRL21=L2*LR
1690 PRINT #1,""
1700 PRINT #1,""
1710 PRINT #1,"FEEDER",MID$(F$,1,6);MID$(F$,14),CHR$(27)
1720 PRINT #1,TAB(31),"FACILITY","CANDU"
1730 PRINT #1,"D1",TAB(30),FDRD11,FDRDO1
1740 PRINT #1,"D2",TAB(30),FDRD21,FDRDO2
1750 PRINT #1,"X",TAB(30),FDRX1,X
1760 PRINT #1,"Y",TAB(30),FDRY1,Y
1770 PRINT #1,"Z",TAB(30),FDRZ1,Z
1780 PRINT #1,"L1",TAB(30),FDRL11,L1
1790 PRINT #1,"L2",TAB(30),FDRL21,L2
1800 PRINT #1,"TOTAL LENGTH",TAB(30),FDRL1,L
1810 COUNTER=COUNTER+1
1820 WEND
1830 DATA "INLET FEEDER Q21,Q2",9,0,1.5,0
1840 DATA 4,0,0,0,  5,0,0,5
1850 DATA 3.125,0,-2,3.6875,  34.625,0,0,34.625
1860 DATA 45.75,45.75,0,64.6875,    0,206.125,0,206.125
1870 DATA 0,24,0,24,                0,0,134,134
1880 DATA 0,38,-12.375,29.875
1890 '
1900 DATA "OUTLET FEEDER Q21,Q2",5,6,2,2.5
1910 DATA 4,0,0,0,  5,0,0,5
1920 DATA 3.125,0,-2,3.6875,   34.675,0,0,34.675
1930 DATA 32.31,32.31,0,45.6875,      13.44,13.44,0,19
1940  DATA 0,206.125,0,206.125,  0,24,0,24
1950 DATA  0,0,215.375,215.375,  0,27.45,-3,27.844
1960 DATA 5.625,13.9375,-4,3.97
1970 '
1980 DATA "INLET FEEDER K14,K9",4,6,2,2.5
1990 DATA 5.625,9,0,6.625, 0,11.125,-30.5,32.4375
2000 DATA 0,109,0,109,   12,12,0,16.375
2010 DATA 13,13,0,19,   0,30.25,0,30.25
2020 DATA 0,42,0,42,    0,0,98.875,98.875
2030 DATA 0,20,27.5,34,  0,0,23.75,13.6875
2040 '
2050 DATA "OUTLET FEEDER K14,K9",5,4,2.5,3.5
2060 DATA 5.625,9,0,6.625, 0,11.125,-30.5,32.4375
2070 DATA 0,109,0,109,    25,25,0,35.625
2080 DATA 0,30.25,0,30.25, 0,42,0,42
2090 DATA 0,0,166.875,166.875, 0,20,27.5,34,  0,0,35.75,24.5675
2100 '
2110 DATA "INLET FEEDER T12,T11",5,5,2,2.5
2120 DATA 9,5.625,0,6.625,    11.125,0,-30.5,32.4375
2130 DATA 142.5,0,0,142.5,    64.875,64.875,0,91.75
2140 DATA 0,104,0,104,        0,111.125,0,111.125
2150 DATA 0,42,0,42,          0,0,98.875,98.875
2160 DATA 0,20,27.5,32,       0,0,23.75,23.75
2170 '
2180 DATA "OUTLET FEEDER T12,T11",4,6,2.5,3.5
2190 DATA 9,5.625,0,6.625, 11.125,0,-30.5,32.4375
2200 DATA 142.5,0,0,142.5, 32,32,0,45
```

```
2210 DATA 32.875,32.875,0,46.75,     0,215.125,0,215.125
2220 DATA 0,42,0,42, 0,0,166.875,166.875
2230 DATA 0,20,27.5,34,    0,0,23.75,12.5625
2240 '
2250 DATA "INLET FEEDER C14,C9",9,0,2,0
2260 DATA 5.625,9,0,6.625,     0,2.1875,6,6.375
2270 DATA 0,39.1875,0,39.1875, 30.625,30.625,0,43.3125
2280 DATA 0,24.625,0,24.625,   0,18,0,18
2290 DATA 0,0,135.125,135.125, 0,28.375,0,28.375
2300 DATA 0,15.625,-21.5,16.5625
2310 '
2320 DATA "OUTLET FEEDER C14,C9",9,0,2.5,0
2330 DATA 5.625,9,0,6.625,     0,2.1875,6,6.375
2340 DATA 0,39.1875,0,39.1875, 30.625,30.625,0,43.3125
2350 DATA 0,24.625,0,24.625,   0,18,0,18
2360 DATA 0,0,203.125,203.125, 0,28.625,0,28.625
2370 DATA 0,15.625,-21.5,15.5
2380 '
2390 DATA "INLET FEEDER N21,N2",9,0,2,0
2400 DATA 9,5.625,0,6.625,   3.4375,0,2,3.96875
2410 DATA 23.8125,0,0,23.8125,       16.875,16.875,0,23.875
2420 DATA 0,195.625,0,195.625,  0,18,0,18
2430 DATA 0,0,139.125,139.125,  0,28.75,0,28.75
2440 DATA 0,15.625,-21.5625,16.5625
2450 '
2460 DATA "OUTLET FEEDER N21,N2",9,0,2.5,0
2470 DATA 9,5.625,0,6.625,      3.4375,0,2,3.96875
2480 DATA 23.8125,0,0,23.8125,     16.875,16.875,0,23.875
2490 DATA 0,195.625,0,195.625,     0,18,0,18
2500 DATA 0,0,207.125,207.125,      0,28.75,0,28.75
2510 DATA 0,15.625,-21.5,15.5
2520 ' PIPING
2530 POHSGD10=398
2540 POHSGD20=442.9
2550 POHSGD11=POHSGD10*(LR*AFRR^2)^.2
2560 POHSGD21=POHSGD20*(LR*AFRR^2)^.2
2570 PRINT #1,"PIPING"
2580 PRINT #1,"------"
2590 PRINT #1,"OUTLET HEADER TO STEAM GENERATOR",CHR$(27)
2600 POHSGL0=2313
2610 POHSGL1=POHSGL0*LR
2620 PRINT #1,"L",TAB(30),POHSGL1,POHSGL0
2630 PRINT #1,"D1",TAB(30),POHSGD11,POHSGD10
2640 PRINT #1,"D2",TAB(30),POHSGD21,POHSGD20
2650 PRINT #1,""
2660 PRINT #1,"PUMP SUCTION",CHR$(27)
2670 PRINT #1,""
2680 PSGPSD0=442.9
2690 PSGPSD1=PSGPSD0*(LR*AFRR^2)^.2
2700 PSGPSL0=4500
2710 PSGPSL1=PSGPSL0*LR
2720 PRINT #1," L",TAB(30),PSGPSL1,PSGPSL0
2730 PRINT #1,"D1",TAB(30),PSGPSD1,PSGPSD0,CHR$(27)
2740 PRINT #1,""
2750 PRINT #1,"PUMP DISCHARGE"
```

```
2760 PPIHLO=9.9999
2770 PPIHL1=PPIHLO*LR
2780 PPIHDO=354
2790 PPIHD1=PPIHDO*(LR*AFRR^2)^.2
2800 PRINT #1," L",TAB(30),PPIHL1,PPIHLO
2810 PRINT #1,"d1",TAB(30),PPIHD1,PPIHDO,CHR$(27)
2820 CLOSE #1
2830 END
```

MAJOR SYSTEM SCALING PARAMETERS

LENGTH RATIO =	.5
VELOCITY RATIO =	.7071068
HEAT DENSITY RATIO =	1.414214
HYDRAULIC DIA. RATIO =	.8408964
VOLUME RATIO =	9.791675E-02
TOTAL HEAT RATIO =	.1384752
FLOW AREA RATIO =	.1958335
CHANNEL AREA RATIO =	.1918755

TIME RATIO = .7071068

	FACILITY	CANDU
TEST SECTION & CORE		
NUMBER OF CHANNELS PER PASS	5	95
TEST SECTION TUBE I.D	45.29292	103.4
HEATED TEST SECTION LENGTH	2971.8	5943.6
HEATER ROD O.D	13.12	13.12
NUMBER OF HEATER RODS	7	37
CROSS SECTION OF T.S TUBE	1611.204	8397.132
FLOW AREA IN T.S TUBE	664.8454	3394.952
FLOW AREA PER HEATER ROD	94.97791	91.75546
T.S HYDRAULIC DIA.	6.172897	7.340853
T.S. TOTAL POWER	830.8512	6000
END FITTINGS		
LENGTH	1115.309	2230.618
OUTLET HEADER		
LENGTH	2018.125	6458
CROSS SECTION AREA	9815.293	129461.9
I.D	111.791	406
STEAM GENERATOR		
TUBE ID	13.62	13.62
TUBE O.D	15.88	15.88
CROSS SECTION OF EACH TUBE	198.0573	198.0573
LENGTH OF AVERAGE TUBE	9380.704	18761.41
HEIGHT OF AVERAGE TUBE	4690.352	9380.704
INLET HEADER		
LENGTH	2002.188	6407
CROSS SECTION	8151.822	107521
I.D	101.8785	370

INLET FEEDERS

LENGTHS ARE NOT SCALED FROM ANY PARTICULAR FEEDERS
FEEDERS C-9,Q-2,K-9,Q-2 AND T-11 ARE USED TO OBTAIN
REPRESENTAIVE FEEDER GEOMETRIC INFORMATION

FEEDER **INLET Q21,Q2 ^[**

	FACILITY	CANDU
D1	17.27721	38.1
D2	0	0
X	1174.75	2349.5
Y	3986.213	7972.425
Z	1519.237	3038.475
L1	6375.4	12750.8
L2	0	0
TOTAL LENGTH	6375.4	12750.8

FEEDER **OUTLET Q21,Q2 ^[**

	FACILITY	CANDU
D1	23.03629	50.8
D2	28.79536	63.5
X	1246.823	2493.645
Y	4029.234	8058.468
Z	2620.963	5241.925
L1	1130.935	2261.87
L2	6303.188	12606.38
TOTAL LENGTH	7434.122	14868.24

FEEDER **INLET K14,K9 ^[**

	FACILITY	CANDU
D1	23.03629	50.8
D2	28.79536	63.5
X	388.9375	777.875
Y	3128.963	6257.925
Z	1519.237	3038.475
L1	2088.356	4176.713
L2	3020.219	6040.438
TOTAL LENGTH	5108.575	10217.15

FEEDER **OUTLET K14,K9 ^[**

	FACILITY	CANDU
D1	28.79536	63.5
D2	40.3135	88.9
X	388.9375	777.875
Y	3128.963	6257.925
Z	2535.238	5070.475
L1	2717.006	5434.012
L2	3396.52	6793.04
TOTAL LENGTH	6113.526	12227.05

FEEDER **INLET T12,T11** ^[

	FACILITY	CANDU
D1	23.03629	50.8
D2	28.79536	63.5
X	2889.25	5778.5
Y	4414.838	8829.675
Z	1519.237	3038.475
L1	4791.869	9583.738
L2	3908.425	7816.85
TOTAL LENGTH	8700.294	17400.59

FEEDER **OUTLET T12,T11** ^[

	FACILITY	CANDU
D1	28.79536	63.5
D2	40.3135	88.9
X	2889.25	5778.5
Y	4414.838	8829.675
Z	2382.838	4765.675
L1	2877.344	5754.688
L2	6569.869	13139.74
TOTAL LENGTH	9447.212	18894.42

FEEDER **INLET C14,C9** ^[

	FACILITY	CANDU
D1	23.03629	50.8
D2	0	0
X	460.375	920.75
Y	2128.838	4257.675
Z	1519.237	3038.475
L1	4040.981	8081.963
L2	0	0
TOTAL LENGTH	4040.981	8081.963

FEEDER **OUTLET C14,C9** ^[

	FACILITY	CANDU
D1	28.79536	63.5
D2	0	0
X	460.375	920.75
Y	2132.013	4264.025
Z	2382.838	4765.675
L1	4894.262	9788.524
L2	0	0
TOTAL LENGTH	4894.262	9788.524

FEEDER	INLET N21,N2 ^[		
		FACILITY	CANDU
D1		23.03629	50.8
D2		0	0
X		674.6875	1349.375
Y		3562.35	7124.7
Z		1518.444	3036.888
L1		5795.566	11591.13
L2		0	0
TOTAL LENGTH		5795.566	11591.13

FEEDER	OUTLET N21,N2 ^[		
		FACILITY	CANDU
D1		28.79536	63.5
D2		0	0
X		674.6875	1349.375
Y		3562.35	7124.7
Z		2382.838	4765.675
L1		6645.672	13291.34
L2		0	0
TOTAL LENGTH		6645.672	13291.34

PIPING

OUTLET HEADER TO STEAM GENERATOR	^[		
L		1156.5	2313
D1		55.58152	398
D2		61.8519	442.9
PUMP SUCTION ^[			
L		2250	4500
D1		61.8519	442.9 ^[
PUMP DISCHARGE			
L		4.99995	9.9999
d1		49.43683	354 ^[

```
10 ' PROGRAM TO GENERATE FEEDER DRAWINGS & FEEDER SECTION DATA
20 '
30 S=25.4/2
40 SD=25.4
50 '*********************************4
60 DIA1=22.7
70 DIA2=DIA1
80 OPEN "O",#1,"B:ali.SCR"
90 OPEN "o",#2,"b:ali.dat"
100 PRINT #2, " "
110 PRINT #1, "1"
120 '*********************************1
130 PRINT #1,"B:ali"
140 COUNTER=1
150 WHILE COUNTER < 4
160 SC=50
170 SY=4
180 SX=1
190 IF COUNTER=2 THEN SX=4
200 IF COUNTER=3 THEN SX=7
210 READ F$,N1,N2,D1,D2
220 IF COUNTER=1 THEN PRINT #2, F$
230 IF COUNTER=1 THEN PRINT #2, "section #","x","y","z","D":PRINT #
240 X=0:Y=0:Z=0:L=0
250 C$=MID$(STR$(SX),2)+","+MID$(STR$(SY),2)
260 IF COUNTER=1 THEN PRINT #1,"INSERT B:CHA ";C$+"   "
270 IF COUNTER=2 THEN PRINT #1,"INSERT B:CHB ";C$+"   "
280 IF COUNTER=3 THEN PRINT #1,"INSERT B:CHC ";C$+"   "
290 PRINT #1,"trace 0.05";" ";
300 PRINT #1,MID$(STR$(SX),2)+","+MID$(STR$(SY),2);" ";
310 FOR I=1 TO N1
320 READ XL,YL,ZL,LL
330 IF COUNTER=1 THEN PRINT #2,  I;: PRINT #2 ,USING "############.
340 X=X+XL:Y=Y+YL:Z=Z+ZL:L=L+LL
350 ON COUNTER GOSUB 760,860,900
360 NEXT I
370 L1=L
380 IF N2=0 THEN PRINT #1,""
390 IF N2=0 THEN 490
400 FOR J=1 TO N2
410 READ XL,YL,ZL,LL
420 IF COUNTER=1 THEN PRINT #2  J+N1,XL*S,YL*S,ZL*S,DIA2
430 X=X+XL:Y=Y+YL:Z=Z+ZL:L=L+LL
440 ON COUNTER GOSUB 760,860,900
450 NEXT J
460 PRINT #1,""
470 L2=L-L1
480 GOTO 500
490 L2=0
500 '
510 RESTORE 620
520 IF COUNTER=1 THEN PRINT #2, "TOTAL ";:PRINT #2, USING "########
530 C$=MID$(STR$(SX),2)+","+MID$(STR$(SY),2)
540 IF COUNTER=1 THEN PRINT #1,"INSERT B:HDA ";C$+"   "
550 IF COUNTER=2 THEN PRINT #1,"INSERT B:HDB ";C$+"   "
```

```
560 IF COUNTER=3 THEN PRINT #1,"INSERT B:HDC ";C$+"    "
570 COUNTER=COUNTER+1
580 WEND
590 PRINT #1,"INSERT B:BORDER 0,0   "
600 PRINT #1,"TEXT 0.5,1 0.1  X-PERPENDICULAR TO CHANNEL  Y-VERTICAL
610 PRINT #1,"TEXT C 7.12,0.75 0.1  FEEDER A1-I"
620 DATA "INLET FEEDER C09,C14",9,0,2,0
630 DATA 5.625,9,0,6.625,      0,2.1875,6,6.375
640 DATA 0,39.1875,0,39.1875, 30.625,30.625,0,43.3125
650 DATA 0,24.625,0,24.625,    0,18,0,18
660 DATA 0,0,135.125,135.125, 0,28.375,0,28.375
670 DATA 0,15.625,-21.5,16.5625
680 '
690 DATA "OUTLET FEEDER C14,C9",9,0,2.5,0
700 DATA 5.625,9,0,6.625,      0,2.1875,6,6.375
710 DATA 0,39.1875,0,39.1875, 30.625,30.625,0,43.3125
720 DATA 0,24.625,0,24.625,    0,18,0,18
730 DATA 0,0,203.125,203.125, 0,28.625,0,28.625
740 DATA 0,15.625,-21.5,15.5
750 END
760 AN=3.1415927#/6
770 SX=SX+XL*COS(AN)/SC
780 SY=SY+XL*SIN(AN)/SC
790 SY=SY+YL/SC
800 SX=SX+ZL*COS(AN)/SC
810 SY=SY-ZL*SIN(AN)/SC
820 PRINT #1,MID$(STR$(SX),2)+","+MID$(STR$(SY),2);" ";
830 RETURN
840 PRINT #1," "
850 END
860 SY=SY+YL/SC
870 SX=SX+XL/SC
880 PRINT #1,MID$(STR$(SX),2)+","+MID$(STR$(SY),2);" ";
890 RETURN
900 SY=SY+YL/SC
910 SX=SX+ZL/SC
920 PRINT #1,MID$(STR$(SX),2)+","+MID$(STR$(SY),2);" ";
930 RETURN
```

```
10 ' ^^^
```

```
560 WEND
570 LPRINT " "
580 KF=KF+1
590 WEND
600 END
610 ' SUBROUTINE TO DETERMINE FRICTION FACTOR BY WOOD'S APPROXIMATION O
620 ' COLEBROOK EQUATION (REF. CIV.ENG. DEC. 1966, PP 60-61)
630 ' e/d FOR DRAWN TUBING   0.000025 FOR   70 mm TUBING
640 A=9.399999E-02*ED^.225+.53*ED
650 B=88*ED^.44
660 C=1.62*ED^.134
670 F=A+B*R^(-C)
680 RETURN
```

LOSS COEFF	REYNOLD'S #	ANNULUS O.D
2	100000	67.3145
2	1000000	66.97963
2	1E+07	66.79127
2	1E+08	66.70058
3	100000	67.15405
3	1000000	66.86104
3	1E+07	66.70058
3	1E+08	66.63081
4	100000	67.04242
4	1000000	66.77731
4	1E+07	66.64476
4	1E+08	66.58198

```
10 ' ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
20 '
30 'PROGRAM TO DETERMINE DIMENSIONS OF THE STEAM GENERATOR
40 'FOR THE THERMOSYPHONING FACILITY. THE FRICTION FACTOR IS  A
50 'FUNCTION OF REYNOLD'S NUMBER; THEREFORE A SERIES OF SOLUTIONS
60 'ARE EXAMINED, INCLUDING THE EFFECT OF DIFFERENT K VALUES FOR
70 'THE TUBE BENDS AS DESIGNED IN THE CANDU.
80 '^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
90 '
100 PRINT  "NUMBER OF TUBES BY PRESSURE DROP"
110 PRINT  "--------------------------------"
120 PRINT " "
130 ' POST SCRIPTS C,F,R ARE FOR CANDU,FACILITY AND RATIO.
140 '
150 ' RELATIVE ROUGHNESS
160 ED=.00006
170 EPS=.001
180 ' CANDU  STEAM GENERATOR TUBE DIMENSIONS
190 NC=3550
200 LC=18761
210 DC=13.62
220 ' FACILITY STEAM GENERATOR TUBES HAVE THE SAME DIA AS IN CANDU S.G
230 '
240 DF=DC
250 ' LENGTH RATIO
260 LR=.5
270 LF=LC*LR
280 AR=.1958335
290 VR=LR^.5
300 KF=2
310 PRINT "LOSS COEFF","REYNOLD'S #","NUMBER OF TUBES"
320 WHILE KF<5
330 KC=KF
340 PRINT " "
350 N=5
360 WHILE N<=8
370 REC=10^N
380 R=REC
390 GOSUB 690
400 FC=F
410 NMAX=NC
420 NMIN=1
430 NF=(NMAX+NMIN)/2
440 REF=REC*VR
450 R=REF
460 GOSUB 690
470 FF=F
480 LHS=(KF+FF*LF/(DF))/(KC+FC*LC/(DC))
490 RHS=(95*NF/(NC*AR*5))^2
500 DIFF=ABS(LHS-RHS)
510 IF LHS<RHS THEN NMAX=NF ELSE NMIN=NF
520 IF DIFF > EPS THEN GOTO 430
530 NF=INT(NF+.5)
540 PRINT KF,REC,NF
550 N=N+1
```

```
560 WEND
570 PRINT " "
580 KF=KF+1
590 WEND
600 'PROGRAM TO DETERMINE S.G TUBE NUMBER BY PRORATING THE HEAT LOAD
610 QR=LR^(-.5)
620 NF=NC*AR*QR*5/95
630 NF=INT(NF+.5)
640 PRINT  "NUMBER OF TUBES BY PRORATING THE HEAT LOAD"
650 PRINT  "----------------------------------------"
660 PRINT " "
670 PRINT NF
680 END
690 ' SUBROUTINE TO DETERMINE FRICTION FACTOR BY WOOD'S APPROXIMATION OF
700 ' COLEBROOK EQUATION (REF. CIV.ENG. DEC. 1966, PP 60-61)
710 ' e/d FOR DRAWN TUBING  0.00006 FOR  15mm TUBING
720 A=9.399999E-02*ED^.225+.53*ED
730 B=88*ED^.44
740 C=1.62*ED^.134
750 F=A+B*R^(-C)
760 RETURN
```

NUMBER OF TUBES BY PRESSURE DROP

LOSS COEFF	REYNOLD'S #	NUMBER OF TUBES
2	100000	28
2	1000000	27
2	1E+07	27
2	1E+08	27
3	100000	28
3	1000000	28
3	1E+07	28
3	1E+08	28
4	100000	28
4	1000000	28
4	1E+07	28
4	1E+08	29

NUMBER OF TUBES BY PRORATING THE HEAT LOAD

52

APPENDIX S3-1

```
*ADDFILE,,YANK$$$
*COMDECK USN7JP
      COMMON/USN7/ DISPVOL
*IDENT USERDATA
*ADDFILE,,,
*DECK USBCN7
      SUBROUTINE USBCN7
*CALL ONE
*CALL TWO
*CALL THREE
*CALL SEVEN
C
      PRESS(N)=1449.0
      ENTH(N)=625.0
      RETURN
      END
*DECK USPIPOS
      SUBROUTINE USPIPOS (ITAMBIS)
*CALL ONE
*CALL TWO
*CALL THREE
*CALL FIVE
*CALL TWENTY2
C
      ITAMBIS=0
      IF(ITYPE(N).NE.2) GO TO 10
      TAMBOS(N)=480.
      HTCOS(N)=2712.
      RETURN
   10 CONTINUE
      TAMBOS (N) = 68.0
      HTCOS (N) = 0.0
      RETURN
      END
*DECK USQ
      SUBROUTINE USQ
*CALL THREE
*CALL NINE
*CALL TWENTY2
*CALL TWENTY3
      QTOTAL(N)=QPIPEIS(N)+QFUEL(N)
      RETURN
      END
*DECK USQG
      SUBROUTINE USQG
*CALL ONE
*CALL TWO
*CALL THREE
*CALL TWENTY3
C
C
      QGAVG(N)=1.0
      QGHOT(N)=1.0
      RETURN
      END
      SUBROUTINE USMAP(IUSMAP)
*DECK USMAP
*CALL THREE
*CALL FIVE
*CALL SIX
*CALL SEVEN
*CALL ONE3
      IUSMAP=1
      MAP(L)=10H
      IF(SIN0(1.E0,0.0) GO TO 10
```

```
      RETURN
10    CONTINUE
      IF(LTYPE(L).EQ.2.OR.LTYPE(L).EQ.3) RETURN
      II=LNODE(L,1)
      JJ=LNODE(L,2)
      I=II
      INDEX=1
      IF(FLOW(L).LT.0.0) GO TO 20
      GO TO 30
20    CONTINUE
      I=JJ
      INDEX=2
30    CONTINUE
      GA=ABS(FLOW(L)/FLAR(L,INDEX))
      IF(GA.LE.50.0.AND.X(I).GT.0.0.AND.X(I).LT.1.0)
     1MAP(L)=10HST
      RETURN
      END
FIREBRD INCLUDE MAIN
TB      TREE     FIREBRD-(INPUT,TRANS)
         END
        J-C AMROUNI        7114.0 BTU/S  PUMP 700FT  OH 625BTU/LB  100%
        1    100.    1000.          5.          40.          1
0.10          .20         .05          1
   1     1    62     1     7     1     1          1     1     1
10000.      10000.      10000.      10000.      10000.      10000.      10000.      10000.
10000.      10000.      10000.      10000.      10000.      10000.      10000.      10000.
10000.      10000.      10000.      10000.      10000.      10000.      10000.      10000.
   1   IHA      .57658      6     4     1.                                          1
   2   IA1      .05775      2           1.                                          1
   3   EA1      .06731      2           1.                                          1
   4   CA1      .06976      2           1.          7.        663.          1.      1
   5   EA1      .06731      2           1.                                          1
   6   OA1      .10948      2           1.                                          1
   7   IA2      .05136      2           1.                                          1
   8   EA2      .06731      2           1.                                          1
   9   CA2      .06976      2           1.          7.        605.          1.      1
  10   EA2      .06731      2           1.                                          1
  11   OA2      .13774      2           1.                                          1
  12   IA3      .09319      2           1.                                          1
  13   EA3      .06731      2           1.                                          1
  14   CA3      .06976      2           1.          7.        831.          1.      1
  15   EA3      .06731      2           1.                                          1
  16   OA3      .20923      2           1.                                          1
  17   IA4      .05136      2           1.                                          1
  18   EA4      .06731      2           1.                                          1
  19   CA4      .06976      2           1.          7.        605.          1.      1
  20   EA4      .06731      2           1.                                          1
  21   OA4      .13774      2           1.                                          1
  22   IA5      .15652      2           1.                                          1
  23   EA5      .06731      2           1.                                          1
  24   CA5      .06976      2           1.          7.        853.          1.      1
  25   EA5      .06731      2           1.                                          1
  26   OA5      .35297      2           1.                                          1
  27   OHA      .6996       6     7     1.                                          1
  28   IPA     1.37817      2           1.                                          1
  29   SGA     1.433        2     2    32.                                          1
  30   OPA     1.37817      2           1.                                          1
  31   PMP     1.           2           1.                    10.                   1
  32   IHB      .57658      6     4     1.                                          1
  33   IB1      .05775      2           1.                                          1
  34   EB1      .06731      2           1.                                          1
  35   CB1      .06976      2           1.          7.        663.          1.      1
  36   EB1      .06731      2           1.                                          1
  37   OB1      .10948      2           1.                                          1
  38   IB2      .05136      2           1.                                          1
  39   EB2      .06731      2           1.                                          1
  40   CB2      .06976      2           1.          7.        605.          1.      1
```

```
41  CB2     .00732      2          1.                                          1
42  OB2     .13774      2          1.                                          1
43  IB3     .09319      2          1.                                          1
44  EB3     .06731      2          1.                                          1
45  CB3     .06976      2          1.          7.        831.        1.        1
46  EB3     .06731      2          1.                                          1
47  OB3     .20923      2          1.                                          1
48  IB4     .05136      2          1.                                          1
49  EB4     .06731      2          1.                                          1
50  CB4     .06976      2          1.          7.        605.        1.        1
51  EB4     .06731      2          1.                                          1
52  OB4     .13774      2          1.                                          1
53  IB5     .15652      2          1.                                          1
54  EB5     .06731      2          1.                                          1
55  CB5     .06976      2          1.          7.        853.        1.        1
56  EB5     .06731      2          1.                                          1
57  OB5     .35297      2          1.                                          1
58  OHB     .6996       6     7    1.                                          1
59  IPB    1.37817      2          1.                                          1
60  SGB    1.433        2     2   32.                                          1
61  OPB    1.37817      2          1.                                          1
62  PMP    1.           2          1.          10.                             1
 1                                -1.
 1      .00436    .07447   13.258      -6.98491    20.0        .0001
 2      .00436    .07447                           1.          .0001
 2
 2      .0119     .03806    3.65814                 1.          .0001
 3      .0119     .03806                            1.          .0001
 3
 3      .00715    .02013    4.87533                 4.          .0001
 4      .00715    .02013                            1.          .0001
 4
 4      .00715    .02013    4.87533                 3.          .0001
 5      .00715    .02013                            1.          .0001
 5
 5      .0119     .03806    3.65814                 1.          .0001
 6      .0119     .03806                            1.          .0001
 6  1                              1.
 6      .00682    .09318   16.056       6.98491     5.9         .0001
27      .00682    .09318                            1.          .0001
 7                                -1.
 1      .00247    .0561    20.777     -10.266       5.9         .0001
 7      .00247    .0561                             1.          .0001
 8
 7      .0119     .03806    3.65814                 1.          .0001
 8      .0119     .03806                            1.          .0001
 9
 8      .00715    .02013    4.87533                 4.          .0001
 9      .00715    .02013                            1.          .0001
10
 9      .00715    .02013    4.87533                 3.          .0001
10      .00715    .02013                            1.          .0001
11
10      .0119     .03806    3.65814                 1.          .0001
11      .0119     .03806                            1.          .0001
12  1                              1.
11      .00432    .07415    3.71063     1.34514     3.1         .0001
27      .00687    .0935    17.72638     8.9206      3.8         .0001
13                               -1.
 1      .00436    .07448    6.85039    -5.79068     6.1         .0001
12      .00639    .09022    9.908      -4.47179     6.8         .0001
14
12      .0119     .03806    3.65814                 1.          .0001
13      .0119     .03806                            1.          .0001
15
13      .00715    .02013    4.87533                 4.          .0001
14      .00715    .02013                            1.          .0001
16
```

14	.00715	.02013	4.87533		3.	.0001
15	.00715	.02013			1.	.0001
17						
15	.0119	.03806	3.65814		1.	.0001
16	.0119	.03806			1.	.0001
18	1		1.			
16	.00682	.09318	8.91404	8.33826	4.8	.0001
27	.01332	.13025	11.14173	1.92717	4.1	.0001
19			-1.			
1	.00247	.0561	20.777	-10.266	5.9	.0001
17	.00247	.0561			1.	.0001
20						
17	.0119	.03806	3.65814		1.	.0001
18	.0119	.03806			1.	.0001
21						
18	.00715	.02013	4.87533		4.	.0001
19	.00715	.02013			1.	.0001
22						
19	.00715	.02013	4.87533		3.	.0001
20	.00715	.02013			1.	.0001
23						
2	.0119	.03806	3.65814		1.	.0001
21	.0119	.03806			1.	.0001
24	1		1.			
21	.00432	.07415	3.71063	1.34514	3.1	.0001
27	.00687	.0935	17.72638	8.9206	3.8	.0001
25			-1.			
1	.00439	.0748	15.72179	-7.27034	6.8	.0001
22	.00682	.09318	12.82152	-7.21457	6.1	.0001
26						
22	.0119	.03806	3.65814		1.	.0001
23	.0119	.03806			1.	.0001
27						
23	.00715	.02013	4.87533		4.	.0001
24	.00715	.02013			1.	.0001
28						
24	.00715	.02013	4.87533		3.	.0001
25	.00715	.02013			1.	.0001
29						
25	.0119	.03806	3.65814		1.	.0001
26	.0119	.03806			1.	.0001
30	1		1.			
26	.00682	.09318	9.43898	1.56824	3.1	.0001
27	.01339	.13058	21.55184	12.91667	3.8	.0001
31	1		1.			
27	.01549	.14042	1.9685	.417	.5	.0001
28	.0198	.15879	5.41339	4.504	1.	.0001
32			1.			
28	.05018	.04469	7.69359	7.38189	1.	.0001
29	.05018	.04469	7.69359	7.38189	.9	.0001
33			-1.			
29	.05018	.04469	7.69359	-7.38189	.9	.0001
30	.05018	.04469	7.69359	-7.38189	1.	.0001
34			1.			
30	.01875	.15453	3.	-2.5	.5	.0001
31	.01875	.15453	3.	2.5	.5	.0001
35	0 1		-1.			
31	.01221	.12467	5.0853	-4.92126	.5	.0001
32	.01221	.12467			1.	.0001
36			-1.			
32	.00436	.07447	13.258	-6.98491	20.0	.0001
33	.00436	.07447			1.	.0001
37						
33	.0119	.03806	3.65814		1.	.0001
34	.0119	.03806			1.	.0001
38						
34	.00715	.02013	4.87533		4.	.0001
35	.00715	.02013			1.	.0001

35	.00715	.02013	4.87533		3.	.0001
36	.00715	.02013			1.	.0001
40						
36	.0119	.03806	3.65814		1.	.0001
37	.0119	.03806			1.	.0001
41	1		1.			
37	.00682	.09318	16.056	6.98491	5.9	.0001
58	.00682	.09318			1.	.0001
42			-1.			
32	.00247	.0561	20.777	-10.266	5.9	.0001
38	.00247	.0561			1.	.0001
43						
38	.0119	.03806	3.65814		1.	.0001
39	.0119	.03806			1.	.0001
44						
39	.00715	.02013	4.87533		4.	.0001
40	.00715	.02013			1.	.0001
45						
40	.00715	.02013	4.87533		3.	.0001
41	.00715	.02013			1.	.0001
46						
41	.0119	.03806	3.65814		1.	.0001
42	.0119	.03806			1.	.0001
47	1		1.			
42	.00432	.07415	3.71063	1.34514	3.1	.0001
58	.00687	.0935	17.72638	8.9206	3.8	.0001
48			-1.			
32	.00436	.07448	6.85039	-5.79068	6.1	.0001
43	.00639	.09022	9.908	-4.47179	6.8	.0001
49						
43	.0119	.03806	3.65814		1.	.0001
44	.0119	.03806			1.	.0001
50						
44	.00715	.02013	4.87533		4.	.0001
45	.00715	.02013			1.	.0001
51						
45	.00715	.02013	4.87533		3.	.0001
46	.00715	.02013			1.	.0001
52						
46	.0119	.03806	3.65814		1.	.0001
47	.0119	.03806			1.	.0001
53	1		1.			
47	.00682	.09318	8.91404	8.33826	4.8	.0001
58	.01332	.13025	11.14173	1.92717	4.1	.0001
54			-1.			
32	.00247	.0561	20.777	-10.266	5.9	.0001
48	.00247	.0561			1.	.0001
55						
48	.0119	.03806	3.65814		1.	.0001
49	.0119	.03806			1.	.0001
56						
49	.00715	.02013	4.87533		4.	.0001
50	.00715	.02013			1.	.0001
57						
50	.00715	.02013	4.87533		3.	.0001
51	.00715	.02013			1.	.0001
58						
51	.0119	.03806	3.65814		1.	.0001
52	.0119	.03806			1.	.0001
59	1		1.			
52	.00432	.07415	3.71063	1.34514	3.1	.0001
58	.00687	.0935	17.72638	8.9206	3.8	.0001
60			0 -1.			
32	.00439	.0748	15.72179	-7.27034	6.8	.0001
53	.00682	.09318	12.82152	-7.21457	6.1	.0001
61						
53	.0119	.03806	3.65814		1.	.0001

```
 54      .0119      .03806                                  1.          .0001
 62
 54      .00715     .02013    4.87533                       4.          .0001
 55      .00715     .02013                                  1.          .0001
 63
 55      .00715     .02013    4.87533                       3.          .0001
 56      .00715     .02013                                  1.          .0001
 64
 56      .0119      .03806    3.65814                       1.          .0001
 57      .0119      .03806                                  1.          .0001
 65      1                                 1.
 57      .00682     .09318    9.43898     1.56824           3.1         .0001
 58      .01339     .13058   21.55184    12.91667           3.8         .0001
 66      1                                 1.
 58      .01549     .14042    1.9685       .417             .5          .0001
 59      .0198      .15879    5.41339     4.504             1.          .0001
 67                                        1.
 59      .05018     .04469    7.69359     7.38189           1.          .0001
 60      .05018     .04469    7.69359     7.38189            .9         .0001
 68                                       -1.
 60      .05018     .04469    7.69359    -7.38189            .9         .0001
 61      .05018     .04469    7.69359    -7.38189           1.          .0001
 69                                        1.
 61      .01875     .15453    3.          -2.5              .5          .0001
 62      .01875     .15453    3.           2.5              .5          .0001
 70            1                          -1.
 62      .01221     .12467    5.0853     -4.92126           .5          .0001
  1      .01221     .12467                                  1.          .0001
  2        489.5      25.5          .11          489.5        25.5          .11
551.       9.1          .11    1.E-10
  0          1.       1776.6                       109.          488.          .0125   1.     E-9
 92.        .232        10.9          .11          10.9
  1          .33432      .04921 190.6
  2          .07448      .02625  53.9
  3          .2185       .02625  59.
  4          .14859      .03821  89.2
  5          .2185       .02625  59.
  6          .09318      .02625  77.4
  7          .0561       .02625  69.1
  8          .2185       .02625  59.
  9          .14859      .03821  89.2
 10          .2185       .02625  69.1
 11          .09015      .02625 100.7
 12          .08379      .02625  74.4
 13          .2185       .02625  59.
 14          .14859      .03821  89.2
 15          .2185       .02625  59.
 16          .11377      .02625 113.3
 17          .0561       .02625  69.1
 18          .2185       .02625  59.
 19          .14859      .03821  89.2
 20          .2185       .02625  59.
 21          .09015      .02625 100.7
 22          .08306      .02625 125.9
 23          .2185       .02625  59.
 24          .14859      .03821  89.2
 25          .2185       .02625  59.
 26          .11919      .02625 181.9
 27          .3668       .04921 208.4
 28          .15389      .04921 113.4
 29          .04469      .00371   8.49
 30          .15453      .04921 113.8
 31          .12467      .04921 133.8
 32          .33432      .04921 190.6
 33          .07448      .02625  53.9
 34          .2185       .02625  59.
 35          .14859      .03821  89.2
 36          .2185       .02625  59.
```

37	.07316	.02625	77.9				
38	.0561	.02625	69.1				
39	.2185	.02625	59.				
40	.14859	.03821	89.2				
41	.2185	.02625	69.1				
42	.09015	.02625	100.7				
43	.08379	.02625	74.4				
44	.2185	.02625	59.				
45	.14859	.03821	89.2				
46	.2185	.02625	59.				
47	.11377	.02625	113.3				
48	.0561	.02625	69.1				
49	.2185	.02625	59.				
50	.14859	.03821	89.2				
51	.2185	.02625	59.				
52	.09015	.02625	100.7				
53	.08306	.02625	125.9				
54	.2185	.02625	59.				
55	.14859	.03821	89.2				
56	.2185	.05725	59.				
57	.11919	.02625	181.9				
58	.3668	.04921	208.4				
59	.15389	.04921	113.4				
60	.04469	.00371	8.49				
61	.15453	.04921	113.8				
62	.12467	.04921	133.8				
4	.03281	.04304	9.5				
9	.03281	.04304	9.5				
14	.03281	.04304	9.5				
19	.03281	.04304	9.5				
24	.03281	.04304	9.5				
35	.03281	.04304	9.5				
40	.03281	.04304	9.5				
45	.03281	.04304	9.5				
50	.03281	.04304	9.5				
55	.03281	.04304	9.5				
35	.01	.1	50.	700.	.74	1800.	20.
52.							
70	.01	.1	50.	700.	.74	1800.	20.
52.							
1	1630.	511.	511.	60.			
2	1603.	511.	511.	60.			
3	1599.	510.	510.	60.			
4	1548.	629.	511.	60.			
5	1595.	629.	592.	60.			
6	1590.	629.	592.	60.			
7	1603.	511.	511.	60.			
8	1599.	510.	510.	60.			
9	1548.	629.	511.	60.			
1	1595.	629.	592.	60.			
11	1590.	629.	592.	60.			
12	1603.	511.	511.	60.			
13	1599.	510.	510.	60.			
14	1548.	629.	511.	60.			

	592.		592.	60.
16	1590.	629.		
	592.		592.	60.
17	1603.	511.		
	511.		511.	60.
18	1599.	510.		
	510.		510.	60.
19	1548.	629.		
	511.		511.	60.
2	1595.	629.		
	592.		592.	60.
21	1590.	629.		
	592.		592.	60.
22	1603.	511.		
	511.		511.	60.
23	1599.	510.		
	510.		510.	60.
24	1548.	629.		
	511.		511.	60.
25	1595.	629.		
	592.		592.	60.
26	1590.	629.		
	592.		592.	60.
27	1449.	628.		
	592.		592.	60.
28	1440.	628.		
	592.		592.	60.
29	1413.5	569.		
-3567.	544.	3567.	544.	500.
3	1386.5	511.		
	513.		513.	60.
31	1378.	511.		
	512.		512.	60.
32	1630.	511.		
	511.		511.	60.
33	1603.	511.		
	511.		511.	60.
34	1599.	510.		
	510.		510.	60.
35	1548.	629.		
	511.		511.	60.
36	1595.	629.		
	592.		592.	60.
37	1590.	629.		
	592.		592.	60.
38	1603.	511.		
	511.		511.	60.
39	1599.	510.		
	510.		510.	60.
4	1548.	629.		
	511.		511.	60.
41	1595.	629.		
	592.		592.	60.
42	1590.	629.		
	592.		592.	60.
43	1603.	511.		
	511.		511.	60.
44	1599.	510.		
	510.		510.	60.
45	1548.	629.		
	511.		511.	60.
46	1595.	629.		
	592.		592.	60.
47	1590.	629.		
	592.		592.	60.
48	1603.	511.		
	511.		511.	60.

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   MFA   NOS/BE 1.3          RELEASE499 84-12-14
11.04.42.ACBFDOW  FROM NOS/S.  PRIME TIME
11.04.42.IP  00003136 WURUS - FILL INPUT   , DC 04
11.04.42.ACBFIRE,B0412-ACBIK,T200,IO100,CM220000.
11.04.42.P3.          J. C. AMROUNI
46 11.04.43.ATTACH,FIREBRDJOBCONTROL,ID=UPMARTIN.
11.04.43.LFN IS
11.04.43.FIREBRD
11.04.43.PF CYCLE NO. = 007
11.04.43.PRINTSP,OUTPUT,DEF,UN=P3F4.
11.04.44.FIREBRD,CAT=NO,VERSION=MOD1150.
11.04.45.IFE,FILE(OLDPL,PF).EQ.0.AND.FILE(OLDPL,L
11.04.45.0),EQ.C,USERPL.
11.04.45.  IFE,$MOD1150$.EQ.$MOD1150$.OR.$MOD1150$
11.04.45..EQ.$MOD1250$,JMP1.
11.04.45.ATTACH,OLDPL,FIREBIRD3MOD1150NODESUSERFI
11.04.45.LE,ID=LIN.
11.04.46.PF CYCLE NO. = 003
11.04.46.  SKIP,SKP1.
11.04.46.  ENDIF,SKP1.
11.04.46.ENDIF,USERPL.
11.04.46.
11.04.46.IFE,0,EQ.1,SKIPSI.
11.04.46.ELSE,SKIPSI.'
11.04.46.  UPDATE,F,L=0.
11.04.47.DECK STRUCTURE CHANGED
11.04.48.  UPDATE COMPLETE.
11.04.48.  IFE,$.$.NE.$.$,NOQLST.
11.04.49.  ENDIF,NOQLST.
11.04.49.ENDIF,SKIPSI.
11.04.49.
11.04.49.FTN,I,L=0,R=3,P,OPT=2.
11.05.01.       .237 CP SECONDS COMPILATION TIME
11.05.01.RETURN(COMPILE)
11.05.01.
11.05.01.IFE,FILE(RESTART,PF).EQ.1,NORESTART.
11.05.01.ENDIF,NORESTART.
11.05.01.
11.05.01.IFE,FILE(BIN,PF).EQ.0.AND.FILE(BIN,LO).E
11.05.01.Q.0,COMBINE.
11.05.02.  IFE,$MOD1150$.EQ.$MOD1150$.OR.$MOD1150$
11.05.02..EQ.$MOD1250$,JMP1BIN.
11.05.03.ATTACH,BIN,FIREBIRD3MOD1150NODESBINMAR01
11.05.03.83,ID=LIN.
11.05.03.PF CYCLE NO. = 030
11.05.03.  SKIP,COMBINE.
11.05.04.ENDIF,COMBINE.
11.05.04.
11.05.04.IFE,$NO$.EQ.$PL$.OR.$NO$.EQ.$REPL$,FLUSH
11.05.04..
11.05.05.ENDIF,FLUSH.
11.05.05.
11.05.05.COPYLM,BIN,LGO,LGX,,A.
11.05.05.  UPDATED -- REL    / FIREBRD
11.05.10.  UPDATED -- REL    / USBCR7
11.05.11.  UPDATED -- REL    / USMAP
11.05.12.  UPDATED -- REL    / USPIPOS
11.05.12.  UPDATED -- REL    / USQ
11.05.12.  UPDATED -- REL    / USQG
11.05.13.  COPYL COMPLETE.
11.05.13.RETURN,BIN,LGO.
11.05.14.MAP,FULL.
11.05.14.
11.05.14.IFE,0,EQ.1,EX.
11.05.15.ELSE,EX.
```

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11.05.15. SEGLOAD.
11.05.15. LGX,PL=99999.
11.08.03.RESTART WRITTEN AT PROBLEM TIME
11.08.03.   4.00234375000047  E+001
11.08.04.     STOP  10
11.08.04.     176300 MAXIMUM EXECUTION FL.
11.08.04.     82.828 CP SECONDS EXECUTION TIME.
11.08.04.ENDIF,EX. -
11.08.04.
11.08.04.EXIT,U.
11.08.04.IFE,EF=ARE.OR.$NOMAPS.EQ.$ON$,MAP.
11.08.04.ENDIF,MAP.
11.08.04.
11.08.04.EXIT,U.
11.08.04.IFE,$NO$.EQ.$REPL$.OR.$NO$.EQ.$RE$,PLOT.
11.08.05.ENDIF,PLOT.
11.08.05.IFE,$NO$.EQ.$PL$.OR.$NO$.EQ.$REPL$,CATAL
11.08.05.OG.
11.08.05.ENDIF,CATALOG.
11.08.05.EXIT,U.
11.08.05.
11.08.05.REWIND,INPUT.
11.08.05.SKIPF,INPUT,1,0.
11.08.05.COPYSBF.
11.08.06.IFE,-1.GE.0,FIESH.
11.08.06.ENDIF,FIESH.
11.08.06.SKIP,END.
11.08.06.ENDIF,END.
11.08.06.
11.08.06.REVERT. - TRANSFER CONTROL BACK TO USER
11.08.07.OP   00032768 WORDS - FILE ACBFDOw, DC 40
11.08.07.MS    35840  WORDS  (  243712 MAX USED)
11.08.07.CPA       86.259 SEC.        52.079 ADJ.
11.08.07.IO        31.192 SEC.         3.275 ADJ.
11.08.07.CM    14663.162 KWS.          4.618 ADJ.
11.08.07.SS                           59.973
11.08.07.PP        56.954 SEC.      DATE 85-01-14
11.08.07.EJ  END OF JOB, S.
11.26.31.UCLP, CCTL1     ,       6.044KLNS.
12.25.24.UCLP, EC, LPP3F4,        5.019KLNS.          ** END OF LISTING **
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APPENDIX S3-2

LINK	FLOW (LBM/S)	VAP FLOW (LBM/S)	NODE		MASS (LBM)	SPEC U (BTU/LBM)	SPEC V (FT3/LBM)	TEMP (F)	PRESS (PSI)	FL H (BTU/LBM)	X OR Y (FRAC;F)	FL X (FRAC)	VOID (FRAC)	T WAL (F)
1	6.30	0.00	IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IA1	2	.298E+01	506.2	.1941E-01	519.4	1525.0	511.7	-78.7808	0.0000	0.0000	519
2	6.30	0.00	IA1	2	.298E+01	506.2	.1941E-01	519.4	1525.0	511.7	-78.7808	0.0000	0.0000	519
			EA1	3	.347E+01	506.2	.1942E-01	519.5	1523.0	511.7	-78.5863	0.0000	0.0000	519
3	6.30	0.00	EA1	3	.347E+01	506.2	.1942E-01	519.5	1523.0	511.7	-78.5863	0.0000	0.0000	519
			CA1	4	.269E+01	609.7	.2589E-01	596.1	1500.6	616.9	.0096	.0096	.1028	596
4	6.30	.06	CA1	4	.269E+01	609.7	.2589E-01	596.1	1500.6	616.9	.0096	.0096	.1028	596
			EA1	5	.249E+01	609.5	.2709E-01	594.2	1479.4	616.9	.0144	.0144	.1497	594
5	6.30	.09	EA1	5	.249E+01	609.5	.2709E-01	594.2	1479.4	616.9	.0144	.0144	.1497	594
			UA1	6	.401E+01	609.5	.2730E-01	593.9	1475.9	616.9	.0153	.0153	.1577	593
6	6.30	.10	UA1	6	.401E+01	609.5	.2730E-01	593.9	1475.9	616.9	.0153	.0153	.1577	593
			UHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
7	4.98	0.00	IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IA2	7	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
8	4.98	0.00	IA2	7	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
			EA2	8	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
9	4.98	0.00	EA2	8	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
			CA2	9	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
10	4.98	.20	CA2	9	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
			EA2	10	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
11	4.98	.21	EA2	10	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
			UA2	11	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
12	4.97	.22	UA2	11	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
			UHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
13	7.68	0.00	IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IA3	12	.482E+01	506.1	.1935E-01	519.4	1554.2	511.7	-81.3743	0.0000	0.0000	519
14	7.68	0.00	IA3	12	.482E+01	506.1	.1935E-01	519.4	1554.2	511.7	-81.3743	0.0000	0.0000	519
			EA3	13	.348E+01	506.1	.1936E-01	519.5	1550.5	511.7	-81.0315	0.0000	0.0000	519
15	7.68	0.00	EA3	13	.348E+01	506.1	.1936E-01	519.5	1550.5	511.7	-81.0315	0.0000	0.0000	519
			CA3	14	.265E+01	612.5	.2632E-01	597.5	1517.3	619.9	.0113	.0113	.1167	597
16	7.68	.09	CA3	14	.265E+01	612.5	.2632E-01	597.5	1517.3	619.9	.0113	.0113	.1167	597
			EA3	15	.239E+01	612.2	.2811E-01	594.7	1485.7	619.9	.0184	.0184	.1830	594
17	7.68	.14	EA3	15	.239E+01	612.2	.2811E-01	594.7	1485.7	619.9	.0184	.0184	.1830	594
			UA3	16	.736E+01	612.2	.2843E-01	594.3	1480.5	620.0	.0196	.0196	.1940	594
18	7.67	.15	UA3	16	.736E+01	612.2	.2843E-01	594.3	1480.5	620.0	.0196	.0196	.1940	594
			UHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
19	4.98	0.00	IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IA4	17	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
20	4.98	0.00	IA4	17	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
			EA4	18	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
21	4.98	0.00	EA4	18	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
			CA4	19	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
22	4.98	.20	CA4	19	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
			EA4	20	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
23	4.98	.21	EA4	20	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
			UA4	21	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
24	4.97	.22	UA4	21	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
			UHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591

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LINK	FLOW (LBM/S)	VAP FLOW (LBM/S)	NODE		MASS (LBM)	SPEC U (BTU/LBM)	SPEC V (FT3/LBM)	TEMP (F)	PRESS (PSI)	FL H (BTU/LBM)	X OR Y (FRAC;F)	FL X (FRAC)	VOID (FRAC)	T WAL (F)
25	7.43	0.00	IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IA5	22	.808E+01	506.2	.1937E-01	519.5	1545.0	511.7	-80.5410	0.0000	0.0000	519
26	7.43	0.00	IA5	22	.808E+01	506.2	.1937E-01	519.5	1545.0	511.7	-80.5410	0.0000	0.0000	519
			EA5	23	.347E+01	506.2	.1938E-01	519.5	1541.5	511.7	-80.2058	0.0000	0.0000	519
27	7.43	0.00	EA5	23	.347E+01	506.2	.1938E-01	519.5	1541.5	511.7	-80.2058	0.0000	0.0000	519
			CA5	24	.235E+01	618.2	.2971E-01	596.9	1510.0	626.5	.0249	.0249	.2292	596
28	7.43	.18	CA5	24	.235E+01	618.2	.2971E-01	596.9	1510.0	626.5	.0249	.0249	.2292	596
			EA5	25	.214E+01	617.9	.3146E-01	594.2	1480.3	626.5	.0314	.0314	.2804	594
29	7.43	.23	EA5	25	.214E+01	617.9	.3146E-01	594.2	1480.3	626.5	.0314	.0314	.2804	594
			OA5	26	.111E+02	618.0	.3180E-01	593.8	1475.4	626.6	.0327	.0327	.2897	593
30	7.42	.24	OA5	26	.111E+02	618.0	.3180E-01	593.8	1475.4	626.6	.0327	.0327	.2897	593
			OHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
31	31.39	1.11	OHA	27	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
			IPA	28	.411E+02	616.1	.3352E-01	590.2	1435.0	625.0	.0384	.0384	.3346	590
32	31.39	1.21	IPA	28	.411E+02	616.1	.3352E-01	590.2	1435.0	625.0	.0384	.0384	.3346	590
			SGA	29	.736E+02	506.4	.1948E-01	519.3	1424.5	511.5	-69.9870	0.0000	0.0000	510
33	31.39	0.00	SGA	29	.736E+02	506.4	.1948E-01	519.3	1424.5	511.5	-69.9870	0.0000	0.0000	510
			OPA	30	.703E+02	506.4	.1961E-01	519.3	1419.8	511.6	-69.5159	0.0000	0.0000	519
34	31.39	0.00	OPA	30	.703E+02	506.4	.1961E-01	519.3	1419.8	511.6	-69.5159	0.0000	0.0000	519
			PMP	31	.508E+02	506.5	.1967E-01	519.4	1395.9	511.6	-67.2945	0.0000	0.0000	519
35	31.38	0.00	PMP	31	.508E+02	506.5	.1967E-01	519.4	1395.9	511.6	-67.2945	0.0000	0.0000	519
			IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
36	6.30	0.00	IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IB1	33	.298E+01	506.2	.1941E-01	519.4	1525.0	511.7	-78.7808	0.0000	0.0000	519
37	6.30	0.00	IB1	33	.298E+01	506.2	.1941E-01	519.4	1525.0	511.7	-78.7808	0.0000	0.0000	519
			EB1	34	.347E+01	506.2	.1942E-01	519.5	1523.0	511.7	-78.5863	0.0000	0.0000	519
38	6.30	0.00	EB1	34	.347E+01	506.2	.1942E-01	519.5	1523.0	511.7	-78.5863	0.0000	0.0000	519
			CB1	35	.269E+01	609.7	.2589E-01	596.1	1500.6	616.9	.0096	.0096	.1028	596
39	6.30	.06	CB1	35	.269E+01	609.7	.2589E-01	596.1	1500.6	616.9	.0096	.0096	.1028	596
			EB1	36	.249E+01	609.5	.2709E-01	594.2	1479.4	616.9	.0144	.0144	.1497	594
40	6.30	.09	EB1	36	.249E+01	609.5	.2709E-01	594.2	1479.4	616.9	.0144	.0144	.1497	594
			OB1	37	.401E+01	609.5	.2730E-01	593.9	1475.9	616.9	.0153	.0153	.1577	593
41	6.30	.10	OB1	37	.401E+01	609.5	.2730E-01	593.9	1475.9	616.9	.0153	.0153	.1577	593
			OHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
42	4.98	0.00	IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IB2	38	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
43	4.98	0.00	IB2	38	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
			EB2	39	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
44	4.98	0.00	EB2	39	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
			CB2	40	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
45	4.98	.20	CB2	40	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
			EB2	41	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
46	4.98	.21	EB2	41	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
			OB2	42	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
47	4.97	.22	OB2	42	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
			OHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
48	7.68	0.00	IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519
			IB3	43	.482E+01	506.1	.1935E-01	519.4	1554.2	511.7	-81.3743	0.0000	0.0000	519
49	7.68	0.00	IB3	43	.482E+01	506.1	.1935E-01	519.4	1554.2	511.7	-81.3743	0.0000	0.0000	519
			EB3	44	.348E+01	506.1	.1936E-01	519.5	1550.5	511.7	-81.0315	0.0000	0.0000	519
50	7.68	0.00	EB3	44	.348E+01	506.1	.1936E-01	519.5	1550.5	511.7	-81.0315	0.0000	0.0000	519
			CB3	45	.265E+01	612.5	.2632E-01	597.5	1517.3	619.9	.0113	.0113	.1167	597
51	7.68	.09	CB3	45	.265E+01	612.5	.2632E-01	597.5	1517.3	619.9	.0113	.0113	.1167	597
			EB3	46	.239E+01	612.2	.2811E-01	594.7	1485.7	619.9	.0184	.0184	.1830	594

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LINK	FLOW (LBM/S)	VAP FLOW (LBM/S)	NODE		MASS (LBM)	SPEC U (BTU/LBM)	SPEC V (FT3/LBM)	TEMP (F)	PRESS (PSI)	FL H (BTU/LBM)	X OR Y (FRAC;F)	FL X (FRAC)	VOID (FRAC)	T WAL (F)
52	7.68	.14	EB3	46	.239E+01	612.2	.2811E-01	594.7	1485.7	619.9	.0184	.0184	.183C	594
			OB3	47	.736E+01	612.2	.2843E-01	594.3	1480.5	620.0	.0196	.0196	.194C	594
53	7.67	.15	OB3	47	.736E+01	612.2	.2843E-01	594.3	1480.5	620.0	.0196	.0196	.194C	594
			OHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
54	4.98	0.00	IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.000C	519
			IB4	48	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.000C	519
55	4.98	0.00	IB4	48	.264E+01	506.2	.1944E-01	519.4	1512.9	511.7	-77.7008	0.0000	0.0000	519
			EB4	49	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.0000	519
56	4.98	0.00	EB4	49	.346E+01	506.3	.1944E-01	519.5	1512.1	511.7	-77.6042	0.0000	0.000C	519
			CB4	50	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
57	4.98	.20	CB4	50	.208E+01	623.9	.3347E-01	595.8	1497.7	633.2	.0396	.0396	.3274	595
			EB4	51	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
58	4.98	.21	EB4	51	.196E+01	623.8	.3433E-01	594.5	1483.7	633.2	.0427	.0427	.3479	594
			UB4	52	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
59	4.97	.22	UB4	52	.399E+01	623.8	.3456E-01	594.2	1480.3	633.3	.0435	.0435	.3532	594
			UHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
60	7.43	0.00	IHB	32	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.000C	519
			IB5	53	.808E+01	506.2	.1937E-01	519.5	1545.0	511.7	-80.5410	0.0000	0.000C	519
61	7.43	0.00	IB5	53	.808E+01	506.2	.1937E-01	519.5	1545.0	511.7	-80.5410	0.0000	0.0000	519
			EB5	54	.347E+01	506.2	.1938E-01	519.5	1541.5	511.7	-80.2058	0.0000	0.0000	519
62	7.43	0.00	EB5	54	.347E+01	506.2	.1938E-01	519.5	1541.5	511.7	-80.2058	0.0000	0.0000	519
			CB5	55	.235E+01	618.2	.2971E-01	596.9	1510.0	626.5	.0249	.0249	.2292	596
63	7.43	.18	CB5	55	.235E+01	618.2	.2971E-01	596.9	1510.0	626.5	.0249	.0249	.2292	596
			EB5	56	.214E+01	617.9	.3146E-01	594.2	1480.3	626.5	.0314	.0314	.2804	594
64	7.43	.23	EB5	56	.214E+01	617.9	.3146E-01	594.2	1480.3	626.5	.0314	.0314	.2804	594
			UB5	57	.111E+02	618.0	.3180E-01	593.8	1475.4	626.6	.0327	.0327	.2897	593
65	7.42	.24	UB5	57	.111E+02	618.0	.3180E-01	593.8	1475.4	626.6	.0327	.0327	.2897	593
			UHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
66	31.39	1.11	UHB	58	.214E+02	616.2	.3264E-01	591.5	1449.0	625.0	.0354	.0354	.3131	591
			IPB	59	.411E+02	616.1	.3352E-01	590.2	1435.0	625.0	.0384	.0384	.3346	590
67	31.39	1.21	IPB	59	.411E+02	616.1	.3352E-01	590.2	1435.0	625.0	.0384	.0384	.3346	590
			SGB	60	.736E+02	506.4	.1948E-01	519.3	1424.5	511.5	-69.9870	0.0000	0.0000	510
68	31.39	0.00	SGB	60	.736E+02	506.4	.1948E-01	519.3	1424.5	511.5	-69.9870	0.0000	0.0000	510
			OPB	61	.703E+02	506.4	.1961E-01	519.3	1419.8	511.6	-69.5159	0.0000	0.0000	519
69	31.39	0.00	OPB	61	.703E+02	506.4	.1961E-01	519.3	1419.8	511.6	-69.5159	0.0000	0.000C	519
			PMP	62	.508E+02	506.5	.1967E-01	519.4	1395.9	511.6	-67.2945	0.0000	0.0000	519
70	31.38	0.00	PMP	62	.508E+02	506.5	.1967E-01	519.4	1395.9	511.6	-67.2945	0.0000	0.0000	519
			IHA	1	.300E+02	505.9	.1920E-01	519.4	1623.6	511.7	-87.3778	0.0000	0.0000	519

CP TIME 86.064
RESTART FILE NO. 1 WAS WRITTEN TO TAPE AT PROBLEM TIME 40.0234
NSTORE NUMBER OF PLOTTING STEPS 0

APPENDIX - S5

INLET FEEDER A1

section #	x	y	z	D
1	71.4	114.3	0.0	22.7
2	0.0	27.8	76.2	22.7
3	0.0	497.7	0.0	22.7
4	388.9	388.9	0.0	22.7
5	0.0	312.7	0.0	22.7
6	0.0	228.6	0.0	22.7
7	0.0	0.0	1716.1	22.7
8	0.0	360.4	0.0	22.7
9	0.0	198.4	-273.1	22.7
TOTAL	**460.4**	**2128.8**	**1519.2**	

OUTLET FEEDER A1-O

section #	x	y	z	D
1	71.4	114.3	0.0	28.4
2	0.0	27.8	76.2	28.4
3	0.0	497.7	0.0	28.4
4	388.9	388.9	0.0	28.4
5	0.0	312.7	0.0	28.4
6	0.0	228.6	0.0	28.4
7	0.0	0.0	2579.7	28.4
8	0.0	363.5	0.0	28.4
9	0.0	198.4	-273.1	28.4
TOTAL	**460.4**	**2132.0**	**2382.8**	

INLET FEEDER A2-I

section #	x	y	z	D
1	50.8	0.0	0.0	17.1
2	63.5	0.0	0.0	17.1
3	39.7	0.0	-25.4	17.1
4	439.7	0.0	0.0	17.1
5	581.0	581.0	0.0	17.1
6	0.0	1760.5	0.0	17.1
7	0.0	304.8	0.0	17.1
8	0.0	0.0	1701.8	17.1
9	0.0	482.6	-157.2	17.1
TOTAL	**1174.8**	**3129.0**	**1519.2**	

OUTLET FEEDER A2-O

section #	x	y	z	D
1	50.8	0.0	0.0	22.6
2	63.5	0.0	0.0	22.6
3	39.7	0.0	-25.4	22.6
4	440.4	0.0	0.0	22.6
5	410.3	410.3	0.0	22.6
6	170.7	170.7	0.0	28.5
7	0.0	1717.6	0.0	28.5
8	0.0	304.8	0.0	28.5
9	0.0	0.0	2437.1	28.5
10	0.0	348.6	-38.1	28.5
11	71.4	177.0	-50.8	28.5
TOTAL	**1246.8**	**3129.0**	**2621.0**	

INLET FEEDER A3-I

section #	x	y	z	D
1	71.4	114.3	0.0	22.7
2	0.0	141.3	-387.3	22.7
3	0.0	1384.3	0.0	22.7
4	152.4	152.4	0.0	22.7
5	165.1	165.1	0.0	27.5
6	0.0	384.2	0.0	27.5
7	0.	533.4	0.0	27.5
8	0.0	0.0	1255.7	27.5
9	0.0	254.0	349.3	27.5
10	0.0	0.0	301.6	27.5
TOTAL	388.9	3129.0	1519.2	

OUTLET FEEDER A3-O

section #	x	y	z	D
1	71.4	114.3	0.0	28.4
2	0.0	141.3	-387.3	28.4
3	0.0	1384.3	0.0	28.4
4	317.5	317.5	0.0	28.4
5	0.0	384.2	0.0	28.4
6	0.0	533.4	0.0	39.7
7	0.0	0.0	1966.9	39.7
8	0.0	254.0	349.3	39.7
9	0.0	0.0	454.0	39.7
TOTAL	388.9	3129.0	2382.8	

INLET FEEDER A4-I

section #	x	y	z	D
1	50.8	0.0	0.0	17.1
2	63.5	0.0	0.0	17.1
3	39.7	0.0	-25.4	17.1
4	439.7	0.0	0.0	17.1
5	581.0	581.0	0.0	17.1
6	0.0	1760.5	0.0	17.1
7	0.0	304.8	0.0	17.1
8	0.0	0.0	1701.8	17.1
9	0.0	482.6	-157.2	17.1
TOTAL	**1174.8**	**3129.0**	**1519.2**	

OUTLET FEEDER A4-O

section #	x	y	z	D
1	50.8	0.0	0.0	22.6
2	63.5	0.0	0.0	22.6
3	39.7	0.0	-25.4	22.6
4	440.4	0.0	0.0	22.6
5	410.3	410.3	0.0	22.6
6	170.7	170.7	0.0	28.5
7	0.0	1717.6	0.0	28.5
8	0.0	304.8	0.0	28.5
9	0.0	0.0	2437.3	28.5
10	0.0	348.6	-38.1	28.5
11	71.4	177.0	-50.8	28.5
TOTAL	**1246.8**	**3129.0**	**2383.0**	

INLET FEEDER A5-I

section #	x	y	z	D
1	114.3	71.4	0.0	22.8
2	141.3	0.0	-387.3	22.8
3	1809.8	0.0	0.0	22.8
4	823.9	823.9	0.0	22.8
5	0.0	1320.8	0.0	22.8
6	0.0	1411.3	0.0	28.4
7	0.0	533.4	0.0	28.4
8	0.0	0.0	1255.7	28.4
9	0.0	254.0	349.3	28.4
10	0.0	0.0	301.6	28.4
TOTAL	**2889.3**	**4414.8**	**1519.2**	

OUTLET FEEDER A5-O

section #	x	y	z	D
1	114.3	71.4	0.0	28.4
2	141.3	0.0	-387.3	28.4
3	1809.8	0.0	0.0	28.4
4	406.4	406.4	0.0	28.4
5	417.5	417.5	0.0	39.8
6	0.0	2732.1	0.0	39.8
7	0.0	533.4	0.0	39.8
8	0.0	0.0	2119.3	39.8
9	0.0	254.0	349.3	39.8
10	0.0	0.0	301.6	39.8
TOTAL	**2889.3**	**4414.8**	**2382.8**	

INLET FEEDER B1-I

section #	x	y	z	D
1	71.4	114.3	0.0	22.7
2	0.0	27.8	76.2	22.7
3	0.0	497.7	0.0	22.7
4	388.9	388.9	0.0	22.7
5	0.0	312.7	0.0	22.7
6	0.0	228.6	0.0	22.7
7	0.0	0.0	1716.1	22.7
8	0.0	360.4	0.0	22.7
9	0.0	198.4	-273.1	22.7
TOTAL	460.4	2128.8	1519.2	

OUTLET FEEDER B1-O

section #	x	y	z	D
1	71.4	114.3	0.0	28.4
2	0.0	27.8	76.2	28.4
3	0.0	497.7	0.0	28.4
4	388.9	388.9	0.0	28.4
5	0.0	312.7	0.0	28.4
6	0.0	228.6	0.0	28.4
7	0.0	0.0	2579.7	28.4
8	0.0	363.5	0.0	28.4
9	0.0	198.4	-273.1	28.4
TOTAL	460.4	2132.0	2382.8	

INLET FEEDER B2-I

section #	x	y	z	D
1	50.8	0.0	0.0	17.1
2	63.5	0.0	0.0	17.1
3	39.7	0.0	-25.4	17.1
4	439.7	0.0	0.0	17.1
5	581.0	581.0	0.0	17.1
6	0.0	1760.5	0.0	17.1
7	0.0	304.8	0.0	17.1
8	0.0	0.0	1701.8	17.1
9	0.0	482.6	-157.2	17.1
TOTAL	1174.8	3129.0	1519.2	

OUTLET FEEDER B2-O

section #	x	y	z	D
1	50.8	0.0	0.0	22.6
2	63.5	0.0	0.0	22.6
3	39.7	0.0	-25.4	22.6
4	440.4	0.0	0.0	22.6
5	410.3	410.3	0.0	22.6
6	170.7	170.7	0.0	28.5
7	0.0	1717.6	0.0	28.5
8	0.0	304.8	0.0	28.5
9	0.0	0.0	2437.1	28.5
10	0.0	348.6	-38.1	28.5
11	71.4	177.0	-50.8	28.5
TOTAL	1246.8	3129.0	2382.8	

INLET FEEDER B3-I

section #	x	y	z	D
1	71.4	114.3	0.0	22.7
2	0.0	141.3	-387.3	22.7
3	0.0	1384.3	0.0	22.7
4	152.4	152.4	0.0	22.7
5	165.1	165.1	0.0	27.5
6	0.0	384.2	0.0	27.5
7	0.	533.4	0.0	27.5
8	0.0	0.0	1255.7	27.5
9	0.0	254.0	349.3	27.5
10	0.0	0.0	301.6	27.5
TOTAL	**388.9**	**3129.0**	**1519.2**	

OUTLET FEEDER B3-O

section #	x	y	z	D
1	71.4	114.3	0.0	28.4
2	0.0	141.3	-387.3	28.4
3	0.0	1384.3	0.0	28.4
4	317.5	317.5	0.0	28.4
5	0.0	384.2	0.0	28.4
6	0.0	533.4	0.0	39.7
7	0.0	0.0	1966.9	39.7
8	0.0	254.0	349.3	39.7
9	0.0	0.0	454.0	39.7
TOTAL	**388.9**	**3129.0**	**2382.8**	

INLET FEEDER B4-I

section #	x	y	z	D
1	50.8	0.0	0.0	17.1
2	63.5	0.0	0.0	17.1
3	39.7	0.0	-25.4	17.1
4	439.7	0.0	0.0	17.1
5	581.0	581.0	0.0	17.1
6	0.0	1760.5	0.0	17.1
7	0.0	304.8	0.0	17.1
8	0.0	0.0	1701.8	17.1
9	0.0	482.6	-157.2	17.1
TOTAL	1174.8	3129.0	1519.2	

OUTLET FEEDER B4-O

section #	x	y	z	D
1	50.8	0.0	0.0	22.6
2	63.5	0.0	0.0	22.6
3	39.7	0.0	-25.4	22.6
4	440.4	0.0	0.0	22.6
5	410.3	410.3	0.0	22.6
6	170.7	170.7	0.0	28.5
7	0.0	1717.6	0.0	28.5
8	0.0	304.8	0.0	28.5
9	0.0	0.0	2437.3	28.5
10	0.0	348.6	-38.1	28.5
11	71.4	177.0	-50.8	28.5
TOTAL	1246.8	3129.0	2383.0	

INLET FEEDER B5-I

section #	x	y	z	D
1	114.3	71.4	0.0	22.8
2	141.3	0.0	-387.3	22.8
3	1809.8	0.0	0.0	22.8
4	823.9	823.9	0.0	22.8
5	0.0	1320.8	0.0	22.8
6	0.0	1411.3	0.0	28.4
7	0.0	533.4	0.0	28.4
8	0.0	0.0	1255.7	28.4
9	0.0	254.0	349.3	28.4
10	0.0	0.0	301.6	28.4
TOTAL	**2889.3**	**4414.8**	**1519.2**	

OUTLET FEEDER B5-O

section #	x	y	z	D
1	114.3	71.4	0.0	28.4
2	141.3	0.0	-387.3	28.4
3	1809.8	0.0	0.0	28.4
4	406.4	406.4	0.0	28.4
5	417.5	417.5	0.0	39.8
6	0.0	2732.1	0.0	39.8
7	0.0	533.4	0.0	39.8
8	0.0	0.0	2119.3	39.8
9	0.0	254.0	349.3	39.8
10	0.0	0.0	301.6	39.8
TOTAL	**2889.3**	**4414.8**	**2382.8**	